THE DETERMINATION OF OPTIMUM NUTRIENT CONCENTRATION RANGES OF NITROGEN, PHOSPHORUS, AND POTASSIUM IN TIFDWARF BERMUDAGRASS (*CYNODON DACTYLON* X *CYNODON TRANSVAALENSIS* L. BURTT-DAVEY) AS RELATED TO GROWTH AND QUALITY

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN HORTICULTURE

AUGUST 1979

By

Terrance Bill Hiroshi Fujimoto

Dissertation Committee:

Charles L. Murdoch, Chairman
Yoshinori Kanehiro
Richard E. Green
Roy K. Nishimoto
Fred D. Rauch

We certify that we have read this dissertation and that in our opinion it is satisfactory in scope and quality as a dissertation for the degree of Doctor of Philosophy in Horticulture.

DISSERTATION COMMITTEE:

Charles L. Murdoch
CHAIRMAN

Yoshinori Kanehiro

Richard E. Green

Roy K. Nishimoto

Fred D. Rauch

Dedicated to the memory of Mr. Bill Teruji Furutani,
a truth seeker, who now lies in the warm waters of a Hawaiian
sea, but is not forgotten by his grandson.

ACKNOWLEDGEMENTS

It would be difficult for me to submit this dissertation without giving acknowledgement to certain persons who have been especially necessary, in various ways, to my efforts to complete this research.

In preparing this work, I have profited greatly from the wide expertise in turfgrasses of my mentor, Dr. Charles Murdoch. His gentle direction throughout this project has spurred me on, especially during those times when the going was rough. It is my hope that my thanks, here, will in some small measure repay his constant encouragement and kindness to me.

Taking valuable time from their busy schedules, Dr. Murdoch, Dr. Yoshinori Kanehiro, Dr. Roy Nishimoto, Dr. Richard Green, and Dr. Fred Rauch provided critical reviews and very helpful suggestions to guide me in carrying out revisions. Moreover, their friendly spirit provided welcome encouragement. From these professors, as well as from Dr. Haruyuki Kamemoto and Dr. Henry Nakasone, I was given valuable guidance, stimulation, and support. They have all contributed substantively to my education and have become models for me of professional excellence and personal integrity. To them, I owe a deep debt of gratitude.

Special acknowledgement is also extended to Mr. Ernest Okazaki and Mr. Roger Watanabe for their valuable assistance in outlining analytical methods, as well as to Mr. Thomas Caranci of the Oahu Country Club and Mr. Choki Yara of the Waialae Country Club for their extraordinary cooperation and generosity in making my field study a reality.

I have also been especially fortunate in the high level of secretarial help that the Department of Horticulture made available to me. My sincere thanks to Ms. Mae Teramoto, Ms. Evelyn Nakasato, and Ms. Lynne Horiuchi, whose secretarial contributions have often gone far beyond the line of duty.

My typist, Ms. Victoria Lee, did a superlative job in typing out the tables and final manuscript. It is a pleasure to acknowledge her competent skills and unflagging enthusiasm.

Mr. Steven Oshiro deserves my special thanks, as he was instrumental in the computer analyses of the data. Countless hours of painstaking manual calculations were obviated, thanks to his fine expertise in computer operations.

The person to whom I owe my most personally special 'mahalo' is my best friend, partner, and wife, Ms. Darlyne Hayashi-Fujimoto. With keen ability, she deciphered my handwritten scrawl and put it into readable form; the original manuscript was readied for submission after many hours of her unselfish service at the typewriter. I am also deeply grateful for her lovingly stiff criticisms, constructive suggestions, and for always being an honest and discerning sounding-board. Most of all, I thank her for supporting me with her heart; without her unmitigated confidence and abundant faith, this undertaking might have been just another pipe-dream.

First, last, and always, the One who made turfgrasses possible is offered my deepest aloha and mahalo.

ABSTRACT

In contrast to the production of crops, where yield is of major importance, turfgrass culture is concerned primarily with aesthetic and utilitarian qualities. Nitrogen (N) has long been known to be the major factor related to these turf qualities. The importance of phosphorus (P), and potassium (K) have also been demonstrated. Fertility levels for these nutrients can be monitored by analysis of turfgrass tissue. N, P, and K nutrient concentration ranges have also been established for at least one turfgrass species. These levels and ranges, however, have not been evaluated for Tifdwarf bermudagrass.

Tifdwarf bermudagrass was grown under glasshouse and outdoor environment conditions on a sand culture system and subjected to various levels of N, P, and K. Characteristic deficiency symptoms were induced for each nutrient being studied. Three parameters were used in evaluating turf quality: visual rating (VR), dried clipping weight (DW), and leaf chlorophyll content (CC). Tissue concentrations of each nutrient were related to these parameters, thus indicating the point at which nutritional deficiency might be manifested. Lending themselves to predicting the occurrence of nutrient deficiency symptoms in Tifdwarf bermudagrass, these relationships served to establish optimum nutrient concentration ranges based on tissue analysis.

For N, noticeable deficiency symptoms occurred as the tissue concentration dropped below 4%; for P, below 0.23%.

Optimum nutrient ranges were obtained by relating visual ratings to tissue nutrient concentrations; these were: for N, 4.0 to 5.0%; for P,

0.23 to 0.40 %; and for K, 1.5 to 2.0%. Glasshouse and outdoor environment conditions produced near identical results.

It was intended that these data be adapted for practical use. Field monitoring studies were thus initiated at two locations to confirm the experimental findings. Modifications of ongoing fertilization programs were made based on the obtained optimum nutrient concentration ranges.

The more precise management of Tifdwarf bermudagrass should be facilitated by tissue analysis. A better indication of the need for N, P, and K and the quantities that have been extracted from the turf tissue can be obtained for this important turfgrass species.

Visual ratings and tissue analysis can be used as aids in making Tifdwarf bermudagrass fertilizer recommendations. Used in combination, visual ratings and tissue analysis are recommended for the professional turf person as a means of monitoring the effectiveness of fertilization programs as well as in diagnosing turfgrass problems.

TABLE OF CONTENTS

		Page
DEDICATION		iii
ACKNOWLEDGEMENTS		iv
ABSTRACT		vi
LIST OF TABLES		x
LIST OF ILLUSTRATIONS		xv
CHAPTER I.	INTRODUCTION	1
CHAPTER II.	REVIEW OF LITERATURE	5
	A. Nitrogen	5
	B. Phosphorus	10
	C. Potassium	13
	D. Nutrient Culture Studies	16
	E. Greenhouse Environment vs. Field Environment	18
CHAPTER III.	MATERIALS AND METHODS	20
	A. Experiment I: Glasshouse Single Nutrient Treatments	20
	B. Experiment II: Outdoor Environment Studies	23
	C. Experiment III: Combination Treatments in Glasshouse	24
	D. Field Monitoring Studies	26
	E. Analysis of Data	27
CHAPTER IV:	RESULTS	
	A. Experiment I: Glasshouse Single Nutrient Treatments	29
	1. Nitrogen Treatments	29
	2. Phosphorus Treatments	44
	3. Potassium Treatments	59

TABLE OF CONTENTS (Cont'd)

Page

B. Experiment II: Outdoor Environment Studies 73

1. Nitrogen Treatments 73
2. Phosphorus Treatments 87
3. Potassium Treatments 102

C. Experiment III: Combination Treatments in Glasshouse 116

D. Field Monitoring Studies 121

CHAPTER V. DISCUSSION AND CONCLUSIONS 139

APPENDIX 161

BIBLIOGRAPHY 196

LIST OF TABLES

Table		Page
1	Treatment levels for N, P and K in ppm	25
2	Combination treatment levels in ppm	25
3	Effects of N levels on visual ratings of turf pots and dried weights, chlorophyll content, and percent composition of N, P, and K, respectively, of leaf tissue of Tifdwarf bermudagrass grown under glasshouse conditions	32
4	Regression equations and correlation coefficients between the evaluation parameters and N levels on Tifdwarf bermudagrass grown under glasshouse conditions	33
5	Regression equations and correlation coefficients for parameters used for evaluation of N treatment effects on Tifdwarf bermudagrass grown under glasshouse conditions	33
6	Effects of P levels on visual ratings of turf pots and dried weights, chlorophyll content, and percent composition of N, P, and K, respectively, of leaf tissue of Tifdwarf bermudagrass grown under glasshouse conditions	47
7	Regression equations and correlation coefficients between the evaluation parameters and P levels on Tifdwarf bermudagrass grown under glasshouse conditions	48
8	Regression equations and correlation coefficients for parameters used to evaluate P treatment effects on Tifdwarf bermudagrass grown under glasshouse conditions	48
9	Effects of K levels on visual ratings of turf pots and dried weights, chlorophyll content, and percent composition of N, P, and K, respectively, of leaf tissue of Tifdwarf bermudagrass grown under glasshouse conditions	61
10	Regression equations and correlation coefficients between the evaluation parameters and K levels on Tifdwarf bermudagrass grown under glasshouse conditions	62

LIST OF TABLES (Cont'd)

Table		Page
11	Regression equations and correlation coefficients for parameters used to evaluate K treatment effects on Tifdwarf bermudagrass grown under glasshouse conditions	62
12	Effects of N levels on visual ratings of turf pots and dried weights, chlorophyll content, and percent composition of N, P, and K, respectively, of leaf tissue of Tifdwarf bermudagrass grown under field conditions	75
13	Regression equations and correlation coefficients between the evaluation parameters and N levels on Tifdwarf bermudagrass grown under field conditions . . .	76
14	Regression equations and correlation coefficients for parameters used to evaluate N treatment effects on Tifdwarf bermudagrass grown under field conditions	76
15	Effects of P levels on visual ratings of turf pots and dried weights, chlorophyll content, and percent composition of N, P, and K, respectively, of leaf tissue of Tifdwarf bermudagrass grown under field conditions.	90
16	Regression equations and correlation coefficients between the evaluation parameters and P levels on Tifdwarf bermudagrass grown under field conditions	91
17	Regression equations and correlation coefficients for parameters used to evaluate P treatment effects on Tifdwarf bermudagrass grown under field conditions	91
18	Effects of K levels on visual ratings of turf pots and dried weights, chlorophyll content, and percent composition of N, P, and K, respectively, of leaf tissue of Tifdwarf bermudagrass grown under field conditions	104
19	Regression equations and correlation coefficients between the evaluation parameters and K levels on Tifdwarf bermudagrass grown under field conditions	105

LIST OF TABLES (Cont'd)

Table		Page
20	Regression equations and correlation coefficients for parameters used to evaluate K treatment effects on Tifdwarf bermudagrass grown under field conditions	105
21	Overall means of combination treatments	118

LIST OF APPENDIX TABLES

22	Anova for visual ratings as affected by N levels (glasshouse)	162
23	Anova for dry weight yields as affected by N levels (glasshouse)	162
24	Anova for chlorophyll content as affected by N levels (glasshouse)	163
25	Anova for %N as affected by N levels (glasshouse)	163
26	Anova for %P as affected by N levels (glasshouse)	164
27	Anova for %K as affected by N levels (glasshouse)	164
28	Anova for visual ratings as affected by P levels (glasshouse)	165
29	Anova for dry weight yields as affected by P levels (glasshouse)	165
30	Anova for chlorophyll content as affected by P levels (glasshouse)	166
31	Anova for %N as affected by P levels (glasshouse)	166
32	Anova for %P as affected by P levels (glasshouse)	167
33	Anova for %K as affected byP levels (glasshouse)	167
34	Anova for visual ratings as affected by K levels (glasshouse)	168

LIST OF APPENDIX TABLES (Cont'd)

Table		Page
35	Anova for dry weight yields as affected by K levels (glasshouse)	168
36	Anova for chlorophyll content as affected by K levels (glasshouse)	169
37	Anova for %N as affected by K levels (glasshouse)	169
38	Anova for %P as affected by K levels (glasshouse)	170
39	Anova for %K as affected by K levels (glasshouse)	170
40	Anova for visual ratings as affected by N levels (field)	171
41	Anova for dry weight as affected by N levels (field)	171
42	Anova for chlorophyll content as affected by N levels (field)	172
43	Anova for %N as affected by N levels (field)	172
44	Anova for %P as affected by N levels (field)	173
45	Anova for %K as affected by K levels (field)	173
46	Anova for visual ratings as affected by P levels (field)	174
47	Anova for dry weights as affected by P levels (field)	174
48	Anova for chlorophyll content as affected by P levels (field)	175
49	Anova for %N as affected by P levels (field)	175
50	Anova for %P as affected by P levels (field)	176
51	Anova for %K as affected by P levels (field)	176
52	Anova for %P as affected by K levels (field)	177
53	Anova for %K as affected by K levels (field)	177

LIST OF APPENDIX TABLES (Cont'd)

Table		Page
54	Anova for chlorophyll content as affected by K levels (field).	178
55	Anova for %N as affected by K levels (field)	178
56	Anova for visual ratings as affected by K levels (field)	179
57	Anova for dry weights as affected by K levels (field)	179
58	Anova for visual ratings as affected by varying P and K levels	180
59	Anova for dry weights as affected by varying levels of P and K.	181
60	Anova for chlorophyll content as affected by varying P and K levels	182
61	Anova for %N as affected by varying P and K levels	183
62	Anova for %P as affected by varying levels of P and K.	184
63	Anova for %K as affected by varying levels of P and K.	185

LIST OF ILLUSTRATIONS

Figure		Page
1	The effect of N levels on visual ratings	34
2	The effect of N levels on dry weight yields.	35
3	The effect of N levels on chlorophyll content.	36
4	The effect of N levels on percent N in tissue.	37
5	The relationship between visual ratings and dry weight yields.	39
6	The relationship between visual ratings and chlorophyll content.	40
7	The effect of percent N on visual ratings.	41
8	The effects of percent N on dry weight yields.	42
9	The effect of percent N on chlorophyll content	43
10	The effects of P levels on visual ratings.	49
11	The effect of P levels on dry weight yields.	50
12	The effects of P levels on chlorophyll content	51
13	The effect of P levels on percent P in the tissue. . . .	52
14	The relationship between visual ratings and dry weights.	54
15	The relationship between visual ratings and chlorophyll content.	55
16	The effects of percent P on visual ratings	56
17	The effects of percent P on dry weight yields.	57
18	The effect of percent P on chlorophyll content	58
19	The effects of K levels on visual ratings.	63
20	The effect of K levels on dry weight yields.	64
21	The effect of K levels on chlorophyll content.	65
22	The effect of K levels on percent K in the tissue. . . .	66

LIST OF ILLUSTRATIONS (Cont'd)

Figure		Page
23	The relationship between visual ratings and dry weight	68
24	The relationship between visual ratings and chlorophyll	69
25	The effect of percent K on visual ratings	70
26	The effect of percent K on dry weight yields	71
27	The effect of percent K on chlorophyll content	72
28	The effect of N levels on visual ratings	77
29	The effect of N levels on dry weight yields	78
30	The effect of N levels on chlorophyll content	79
31	The effect of N levels on percent N in tissue	80
32	The relationship between visual ratings and dry weight yields	82
33	The relationship between visual ratings and chlorophyll content	83
34	The effect of percent N on visual ratings	84
35	The effect of percent N on dry weight yields	85
36	The effect of percent N on chlorophyll content	86
37	The effect of P levels on visual ratings	92
38	The effect of P levels on dry weight yields	93
39	The effect of P levels on chlorophyll content	94
40	The effect of P levels on percent P in tissue	95
41	The relationship between visual ratings and dry weight yields	97
42	The relationship between visual ratings and chlorophyll content	98
43	The effects of percent P on visual ratings	99
44	The effect of percent P on dry weight yields	100

LIST OF ILLUSTRATIONS (Cont'd)

Figure		Page
45	The effect of percent P on chlorophyll content.	101
46	The effect of K levels on visual ratings.	106
47	The effect of K levels on dry weight yields	107
48	The effect of K levels on chlorophyll content	108
49	The effect of K levels on percent K in tissue	109
50	The relationship between visual ratings and chlorophyll content	111
51	The relationship between visual ratings and chlorophyll content	112
52	The effect of percent K on visual ratings	113
53	The effect of percent K on dry weight yields.	114
54	The effect of percent K on chlorophyll content.	115
55	The effects of varying P and K levels on visual ratings.	119
56	The effects of varying P and K levels on percent N in tissue	120
57	Field monitoring program, green no. 11, Waialae Country club.	123
58	Field monitoring program, green no. 13, Waialae Country Club.	124
59	Field monitoring program, green no. 14, Waialae Country Club.	125
60	Field monitoring program, green no. 18, Waialae Country Club.	126
61	Field monitoring program, green no. 11, Waialae Country Club.	127
62	Field monitoring program, green no. 13, Waialae Country Club.	128
63	Field monitoring program, green no. 14, Waialae Country Club.	129

LIST OF ILLUSTRATIONS (Cont'd)

Figure		Page
64	Field monitoring program, green no. 18, Waialae Country Club	130
65	Field monitoring program, green no. 2, Oahu Country Club	131
66	Field monitoring program, green no. 6, Oahu Country Club	132
67	Field monitoring program, green no. 7, Oahu Country Club	133
68	Field monitoring program, green no. 9, Oahu Country Club	134
69	Field monitoring pr!gram, green no. 2, Oahu Country Club	135
70	Field monitoring program, green no. 6, Oahu Country Club	136
71	Field monitoring program, green no. 7, Oahu Country Club	137
72	Field monitoring program, green no. 9, Oahu Country Club	138

LIST OF APPENDIX ILLUSTRATIONS

73A.	Effects of varying N levels under glasshouse conditions. .	187
73B.	Effects of varying N levels under outdoor environment conditions	187
74A.	Effects of varying P levels under glasshouse conditions. .	189
74B.	P deficiency symptoms.	189
75A.	Effects of varying P levels under outdoor environment conditions	191
75B.	P deficiency symptoms (outdoor environment).	191
76A.	Effects of varying K levels under glasshouse conditions. .	193
76B.	K deficiency symptoms.	193

LIST OF APPENDIX ILLUSTRATIONS (Cont'd)

Figure | Page

77A. Effects of varying K levels under outdoor environment conditions 195

77B. K deficiency symptoms (outdoor environment). 195

CHAPTER I

Introduction

Turfgrass nutrition involves much more than the simple application of fertilizers; nutrient levels, growing media, pH, salinity, watering programs, fertilizer characteristics, and temperature are but a few of the many interacting factors which influence nutrient uptake and fertilizer response. As aids to diagnose turf problems, soil analysis and evaluation of turfgrass appearance are the techniques most widely used; plant tissue analysis, on the other hand, has been generally overlooked (Robey and Duble 1977a).

The development of plant tissue testing as a means of obtaining from the plant itself information about its nutrient status has greatly facilitated research efforts in the field of plant physiology (Branson 1966, Duble 1977a, Knoop 1972 and Oertli 1963). Refinements in chemical and mechanical aspects of this technique have transformed it into a powerful tool for the investigation of plant nutrition-related problems. In particular, tissue analysis has been successfully employed when circumvention of the limitations inherent to soil analysis and evaluation of turfgrass appearance is deemed necessary. Although soil analysis has served well as a primary method with which to determine nutrient availability in the growing medium, it has sometimes been misleading in that nutrients have been shown to be present yet unavailable to the plant (Menn and McBee 1970). Evaluation of turfgrass appearance has similarly yielded spurious results; characteristics of a highly subjective method of appraisal, one observer may consider the condition of a given area to be satisfactory, while another may have a diverse opinion (Mantell and Stanhill 1966). It is believed by a number of researchers studying turfgrass nutrition that tissue analysis can give a better and more objective indication of the plant's need for certain nutrients and ability to absorb nutrients from the growing media (Hylton, Williams, Ulrich, and Cornelius 1964, Ulrich and Hills 1967, Farhoomand and Peterson 1968, among others).

Moreover, in the practical realm, tissue analysis has served as an invaluable aid in the monitoring of fertilization programs and in remediating injury and pathology induced by nutritional deficiencies and excesses (Duble 1977b). For those involved in turf production and management, malnutrition is often a matter of prime concern. By helping to predict nutritional disorders before visual symptoms become apparent, tissue analysis, complemented by other analytical techniques, can provide more cost-effective, efficient, and accurate checks on the nutrient status of the turf. With these considerations in mind, Menn and McBee were successful in employing this technique to determine optimal nutrient ranges in turfgrass leaf tissue as well as tissue levels of certain nutrients at which deficiences would become visible in Tifgreen bermudagrass. Besides this work done in 1970, only a minimum of data is said to exist from which the appearance of turf could be predicted based upon tissue analysis (Menn and McBee 1970).

At the present time there are virtually no detailed records of experiments on the nutritional aspects of turfgrasses in Hawaii. Of particular note is the lack of any experimental data on the nutritional requirements of Tifdwarf bermudagrass (Cynodon dactylon x C. transvaalensis L. Burtt-Davey), a popular turfgrass species grown in Hawaii and other tropical and sub-tropical regions. In Hawaii, Tifdwarf bermudagrass is extensively used on golf course putting greens, fine lawns, and other areas requiring high quality turf, which are built and designed for their aesthetic value and are subject to intensive management. A significant part of this management is the frequent application of nitrogen (N), phosphorus (P), and potassium (K) fertilizers; much time and effort have been expended and considerable expense has been incurred in the maintenance of the aesthetic and utilitarian values of these turf areas. The management of this important turf species then would be greatly facilitated by a better knowledge of its nutritional requirements; the pragmatic importance of such knowledge is quickly recognized and easily acknowledged by agricultural specialists, golf course superintendents, professional turf managers, commercial sod growers, and professional lawn service operators. Certainly, the demand of high quality turf, together with the ever-increasing cost of fertilizer materials and the need to conserve fertilizer resources and curb environmental pollution, would justify turfgrass leaf tissue analysis as an adjunct to soil analysis and evaluation of turfgrass appearance.

In view of the popularity and year-round verdure of Tifdwarf bermudagrass and the fundamental importance of the macronutrient triad, N-P-K, to its nutrition, that such a paucity of research and information, basic and applied, exists is surprising. These considerations as well as those cited earlier prompted the undertaking of the present investigation of the nutritional aspects of Tifdwarf bermudagrass. Specifically, the goal of this investigation was to seek answers to the following:

(1) What responses, relative to the visual quality, growth, and color of turf and the elemental composition of N, P, and K in the turf leaf tissue, will be exhibited with increasing levels of applied N, P, and K to the growing medium?

(2) Are the differences in turf responses significant between increments of applied nutrients, taken separately and in combination?

(3) Do the relationships between the elemental composition of N, P, and K in turf leaf tissue and the aesthetic parameters of visual quality, growth, and color lend themselves to the predictions of the occurrence of nutrient deficiency symptoms?

(4) Can the optimum nutrient range in Tifdwarf bermudagrass leaf tissue be determined? If so, then how?

(5) Are the results obtained for treatments grown under artificial, glasshouse conditions generalizable for use in the field?

(7) How may the person in the field benefit from the obtained experimental findings?

CHAPTER II

Review of Literature

NITROGEN

With the exception of carbon, hydrogen, and oxygen, turfgrasses require N in the largest amount of any of the essential nutrients. N is also readily leached from soils; it is, therefore, applied in the largest amounts in turfgrass fertilization programs. N is a vital constituent of 1) the chlorophyll molecule, which is involved in photosynthesis; 2) amino acids and proteins, which compose a major portion of the protoplasm; 3) nucleic acids, which function in hereditary transfer of plant characteristics; and 4) enzymes and vitamins, which catalyze metabolic reactions within the plant (Beevers 1976). All are vitally important in the growth and development of turfgrasses. Bidwell (1974) and Salisbury and Ross (1969) also describe biochemical roles of N in plant cells.

Beard (1975) lists a number of ways in which N nutrition can affect turf. These include effects on 1) shoot growth, 2) root growth, 3) shoot density, 4) color, 5) disease proneness, 6) heat, cold and drought hardiness, 7) recuperative potential, and 8) composition of the turf community.

If no nutrient deficiency prevails, turfgrasses can contain from 3 to 6 percent total N on a dry matter basis (Beard 1973).

N can also have substantial influences on the growth of turfgrasses. As the N level is increased from zero, there is an increase in growth of roots and shoots. Respiration rate is also increased. Walker and Ward (1974) found that net photosynthesis and dark respiration increased as N fertilization was increased. With increasing levels of N, however, this overall plant response does not continue. A point is reached at which N growth stimulation where the carbohydrates available for protein synthesis becomes limiting. Past research shows that N fertilization, particularly at high rates, stimulates top growth at the expense of root growth. Graber (1931) conducted fertilizer experiments in conjunction with clipping removal observations. When regeneration of N deficient grass was attempted by constant stimulation with fertile soil or by an abundant supply of nitrogenous fertilizer, the carbohydrate reserves were rapidly consumed. With slight opportunity for replenishment, such low carbohydrate levels often become the principle factor which limits growth. Excess N can result in a gradual carbohydrate starvation to a point beyond which plants would not be able to maintain themselves (Harrison 1931). The soluble carbohydrate content of grasses was found to be markedly reduced upon application of several nitrogenous fertilizers (Jones, Griffith, and Walters 1965). This depression was presumed to be largely attributable to the acceleration in growth rate which accompanies the use of nitrogenous fertilizers. Changes in total nitrogen, soluble nitrogen, and soluble carbohydrate contents of ryegrass were followed after application of ammonium sulfate and sodium nitrate (Nowakowski 1962). The application of nitrogenous fertilizer decreased the soluble carbohydrate content of the grass, especially the fructosan content. N application was found to have little effect on the content of soluble sugars (glucose + fructose + sucrose), but to greatly decrease the fructosan. The pattern of changes in the total carbohydrate content followed that of the fructosan content. At higher N levels, there was a rapid turnover of carbohydrate for growth; there was, therefore, less stored carbohydrate, resulting in increased top growth (Adams, Bryan, and Walker 1974). Turf grown under high fertility conditions were found to maintain smaller carbohydrate pools, although the turnover rate of these pools was greater than in turf under low fertility conditions (Hull and Smith 1974). In fertilizer trials, Bocker and Van Boberfield (1974) found that roots from unfertilized plots were significantly more developed.

Juska and Hanson (1967) have suggested thatN be applied in accordance with the needs of the grass. Overstimulation, which follows heavy applications of N, can be more serious in areas that cannot be irrigated during periods of stress.

The level of N can also affect the severity of disease development. In order to vary the levels of N and osmotic pressures, solution culture experiments were conducted in growth chambers by Cheeseman, Roberts, and Tiffany (1965); they found that the average number of lesions produced by Helminthosporium sativum increased with increasing levels of nitrogen and decreasing levels of moisture stress. Leaf spot incidence was found to be most prevalent in the spring and fall on Kentucky bluegrass with higher rates of N (4 pounds of N per 1000 square feet) (Juska and Hanson 1967).

Hardiness to stress such as cold and drought is also influenced by N levels. The degree to which the turf tissue is hydrated is directly correlated with N levels. Pellet and Roberts (1963) found that turf grown on low N was more resistant to high temperature than that on high N. It was concluded by Markland and Roberts (1969) that N level and N source produced sufficiently large differences in yield, percentage dry weight, and mineral composition to be important in maintaing turfgrass quality, as indicated by such criteria as resistance to wilting and disease.

Environmental effects play a significant role in the physiological and color aspects of turfgrasses. Fall and winter N fertilization of bentgrass and fescue was studied in order to investigate the possibility of maintaining green foliage throughout the winter (Powell, Blaser, and Schmidt 1967). Desireable turf color was maintained throughout the winter without adverse physiological changes. Liberal N did not seriously reduce soluble carbohydrates in these grasses, as low temperatures restricted top growth much more than photosynthesis. Duff (1974) found very
similar
smiliar results on bluegrass.

The level of N nutrition is directly correlated with color and shoot density (Madison 1960). The overall aesthetic quality of a lawn, however, depends upon the interaction of many factors, including soil water, nitrogen fertilization, and mowing frequency and height (Madison and Hagan 1962). A combination of treatments aimed at stimulating growth (high N, frequent irrigation, and short or frequent mowing) resulted in a decrease in growth and verdure. It was, therefore, suggested again that yield is decreased in one instance by an exhaustion of carbohydrate, in the other by accumulation of carbohydrate. Mowing height, irrigation frequency, and aeration treatments have significant effects on the water extraction by the turf (Madison 1962). Soil water extraction per turf plant was found to be directly proportional to the height of mowing. Frequent irrigation also resulted in sparse and shallower rooting.

The form of N applied to grasses may have an effect on its growth rate. In sand culture studies, Harrison (1931) found that Kentucky bluegrass grown with high levels of ammonium and low levels of nitrate N developed long, dark green leaves, while those supplied with solutions high in nitrate and low in ammonium N had shorter, lighter green leaves.

N-Soil Relationships

Although turfgrasses can absorb ammonium (NH_4^+) forms, N is primarily absorbed in the nitrate (NO_3^-) form. N uptakeis rapid with translocation to the leaf tissue occurring within 15 hours (McCool and Cook 1930). A major portion of the N utilized by plants is obtained from the soil. The source of N is from the decomposition of soil organic matter or, more commonly, from the application of fertilizers (Tisdale and Nelson 1975).

N can be lost from the soil by leaching and volatilization, unless it is held in organic forms other than urea. N loss by leaching occurs primarily in the nitrate form (Benson and Barnette 1939). The extent of leaching depends on the amount of precipitation and irrigation, temperature, and soil texture. Excessive applications of water soluble N fertilizers should be avoided to minimize the leaching of nitrates that can contribute to nitrate pollution of the ground water, streams, and lakes.

Elkine and Hoveland (1977) and Smika, Heerman, Duke, and Bathchelder (1977) found that nitrate-N movement through sandy soils is dependent on the source of the NO_3^- -N and water movement through the soil. The actual amount of NO_3^- -N that will move through the soil is proportional to the concentration of NO_3^- -N in the soil and the amount of water that moves through the soil. Similar results were also found by Benson and

Barnette (1939). When reasonable N fertilization programs are followed on turf, there is not a significant potential for NO_3^- -N leaching, except on heavily irrigated sands (Reike and Ellis 1974). Brown, Duble, and Thomas (1977) further confirmed that N lossesand concentrations of NO_3^- in the leachate immediately after the application of soluble N sources were a function of the rate of N and water applied. When the irrigation rate was kept at or near the evapotranspiration rate, the loss of NO_3^- from inorganic soluble sources was minimized. Careful application of both N and water, therefore, should reduce leaching of NO_3^- -N at such sites.

Various fungicides that are used on turfgrasses have been shown to inhibit the mineralization of N in soils. Deleterious effects of dithiocarbamate as s-triazine fungicides on mineralization of N in soil have been reported (Dubey and Rodrigues 1970 and Mazur and Hughes 1976). Oxidation of NH_4^+ to NO_3^- is particularly sensitive to these compounds; the inhibition of this process requires that either plants possess the capability to assimilate NH_4^+ or that NO_3^- be supplied through fertilization.

PHOSPHORUS

Contained in all living cells, P is an essential macronutrient. It is involved in a number of physiological functions within the plant, including: 1) energy transformations within the plant in the form of adenosine triphosphate (ATP); 2) a constituent of the genetic material in the cell nucleus; and 3) carbohydrate transformations, such as the conversion of starch to sugar (Beard 1973, Bidwell 1974, and Noggle and Fritz 1975). Found in large amounts in young plant tissues, P is primarily present in the regions of cell division (Hylton, et al. 1965). As a constituent of phytin, P is also present in large quantities in seeds. As a plant matures, the P is transferred to the reproductive portions of the plant, eventually accumulating in the seeds (Tisdale and Nelson 1975).

Affecting the establishment, rooting, maturation, and reproduction, P is an important turfgrass elemental constituent (Beard 1973). It is most vitally needed during the seedling stage of turfgrass growth and development (McVey 1968). P also stimulates root growth and branching (Bredakis 1963 and Juska, et al. 1965). Higher P levels hasten maturity, while P deficiencies retard it. Seed setting is also enhanced by higher P levels, while deficiencies may cause a reduction in tillering, shoot growth, and moisture content of turfgrasses (Hylton et al. 1965).

The quantity of P utilized by turfgrasses is considerably less than that of N and K. Turfgrasses vary in the amount of P absorbed; as examples, Kentucky bluegrass ranks high, while bermudagrass rank low in comparison (Musser 1948).

The accumulation of P in leaves of Merion Kentucky bluegrass was found to exceed that in common bluegrass (Juska, et al. 1965). Read and Ashford (1968) found that Bromegrass absorbed more P than reed canary-grass. Plant growth and absorption of P by Italian ryegrass from nutrient solution was found to be largely determined by the kind and age of leaf tissue sampled (Nylton, et al. 1965). About 750 parts per million (ppm) of hydrogen phosphate (H_2PO_4)-P inthe youngest blade was established as the critical concentration for growth of Italian ryegrass. Lunt, Branson, and Clark (1967) have indicated that about 0.35 percent P in the plant tissue is required for maximum growth of most grasses. Certain species of grasses were found to respond to levels as high as 125 ppm in sand cultures (Bradshaw, Chadwick, Jowett, Lodge, and Swadon 1960).

In studies conducted under controlled conditions, Hall and Miller (1974) concluded that: 1) P availability influenced foliar element concentrations; 2) seasonal fluctuations on foliar element concentrations were significant; and 3) correlations between tissue P content and yield were higher than those between P soil test values and yield.

P-Soil Relationships

Released in soluble form in soils from the weathering of P-bearing minerals and from fertilizers, P recombines, for the most part, with the clay fraction of the soil. The P content usually increases as the clay content increases (Knoop 1972). P is absorbed by plants primarily as the orthophosphate ion ($H_2PO_4^-$) (Tisdale and Nelson 1975). Pyrophosphates may also be equally effective in supplying P to plants (Gilliam 1970). P absorption is greatest at soil pH values of 6 to 7. The concentration of the various phosphate ions in solution is intimately related to the pH of the medium. The $H_2PO_4^-$ ion is favored in more acid media, while the HPO_4^{2-} ion is favored above pH of 7. When iron, aluminum, calcium, and magnesium ions are present, insoluble phosphates of these compounds will be precipitated. Specifically, insoluble phosphates of iron and aluminum in acid soils and of calcium and magnesium in soils of pH values greater than 7 are the compounds which are precipitated (Coleman, Thorup, and Jackson, 1960 and Ragland and Seay 1957).

POTASSIUM

Although it is not a constituent of living cells, K is essential in plant growth and developmental processes. K is involved in: 1) carbohydrate synthesis and translocation; 2) amino acid and protein synthesis; 3) catalyzing numerous enzymatic reactions, including nitrate reduction; 4) regulating transpiration; 5) controlling the uptake of certain nutrients; and 6) regulating the respiration rate (Beard 1973 and Epstein 1972). A K deficiency increases the respiration rate, which in turn causes the depletion of carbohydrate reserves. The rate of transpiration of K-deficient turf is also higher (Beard 1973).

Turfgrasses require K in relatively large amounts, second only to N (Knoop 1972). In actively growing turfgrasses, the K content is at its highest, decreasing as the turf reaches maturity (Hylton, Ulrich, and Cornelius 1967).

Turfgrasses may or may not exhibit visual responses to K, in terms of shoot color, density, or growth (De France 1938). K, however, does influence the following: 1) heat and cold and drought hardiness, 2) rooting, 3) disease proneness, and 4) wear tolerance. Murdoch (1967) suggested that increasing K and reducing N at the approach of hot weather could reduce heat injury to Penncross bentgrass. On the other hand, research by Gilbert and Davis (1967) has shown that K also improves the cold tolerance of Tifdwarf and Tifgreen bermudagrasses. High N and low K gave the least resistance to cold. The greatest winter hardiness came when K levels were almost equal to that of N.

The effects of K and N on winter survival, recovery and disease reaction, and turf quality of bermudagrasses were studied by Juska and

Murray (1974). Applications of K decreased winter injury on these grasses. High K and ammonium nitrate significantly increased bermudagrass recovery from winter injury and increased turf quality.

Increased root development, particularly at higher K levels, was found to improve drought tolerance by Bell and De France (1944) and Holt and Davis (1948). Juska (1965) found that root growth was stimulated more than top growth with added K. The response of roots to increasing K levels was significantly increased in a quadratic fashion, giving maximum fresh weight yields (Markland and Robert 1967). At varying N levels, K was found to substantially increase the weights of roots and rhizomes in Kentucky bluegrass (Monroe, Coortis, and Skogely 1969). Increased foliar growth was the turfgrass response to high K, while increased resistance to high temperature resulted as a response to the combination of high N and K (Pellet and Roberts 1963).

Goss and Gould (1967) have reported that high N and low K results in the accumulation of non-protein nitrogen and unused carbohydrates. They theorize that such a condition favors disease invasion. Ample K was found to suppress Ophiolobus disease in the field. This was further substantiated by Beard (1973) and Markland and Roberts (1969), who found that brown patch, Fusarium patch, <u>Helminthosporium</u> <u>spp</u>., and dollar spot incidences were minimized by higher K levels. Increased proneness to disease, resulting from a K deficiency, is associated with: 1) an excessive accumulation of N and carbohydrates, which provides a favorable media for pathogen activity; 2) a thin, delicate cell wall structure, which is easily crushed during mowing operations and provides ideal penetration and entry sites; 3) changes in the reation and composition of the cell sap, which enhances pathogen activity; and 4) reduced plant vigor.

Turfgrass wear tolerance is reported to increase proportionately with increasing K levels. This has been attributed to the effects of increased K levels on stiffening the leaf blades (Markland and Roberts 1967 and Monroe, et al. 1969). The thicker cell walls, increased plant vigor, high cellulose content, and increased turgor pressure associated with higher K levels may contribute to wear tolerance. Starch accumulation in the stolons of centipedegrass was enhanced by increasing K fertilization, usually at the expense of a lower concentration of simple sugars (Walker and Ward 1974).

K-Soil Relationships

K is a molecular constituent of many soil minerals; as an ion, it is tightly held by clay particles. To be taken up by turfgrasses, K must be in soil solution in the K^+ ion form (Tisdale and Nelson 1975). An equilibrium exists between the K^+ in solution and K^+ held by the clay particles. As the grass root takes up K^+ from the soil solution, additional K^+ is, in turn, released from the clay particles. In similar fashion, when K fertilizer is applied to the soil, K^+ moves from the soil solution to the clay particles. In this way, then, clay particles serve as a reservoir for K^+ and thus help to reduce the amount of K^+ lost by leaching (Duble 1977b). Easily leached from the soil, K^+ may even be leached from the plant when rained upon or by irrigation. The effect of K applications on exchangeable K^+ is influenced by the K fixation and release characteristics of the soil; varying results, therefore, may occur with different soil types (Waddington, Moberg, and

Duich 1972). Added K may interfere with the nitrification of the NH_4^+ in the clay minerals, as K blocks the release of fixed NH_4^+ (Welch and Scott 1960). Conversely, high concentrations of NH_4^+ can reduce the uptake of K^+ by turfgrasses (Duble 1977b). These interactions between N and K can, therefore, have a significant influence on the growth of turfgrasses (Knoop 1972, Duble 1977a, and Duble 1977b).

Nutrient Culture Studies

Artificial or soil-less cultures have been extensively used since the 1930's. They have been extremely useful in many types of investigations on the physiology of plants. At the present time, three types of artificial cultures are used: solution cultures (hydroponics); sand cultures; and gravel cultures (Davidson 1946). Hoagland and Arnon (1950) developed a water culture method for growing plants without soil complete with descriptive methods and procedures. Robins (1946) described the sand culture method of growing plants for experimental purposes. The solution culture method and sand culture methods are widely used in plant nutrition research. More recently, Suzuki and MacLeod (1977) have used hydroponic cultures to study levels of N, P, and K in barley for optimum yields. Extensive sand culture studies were carried out in an attempt to relate anthocyanin content of Kentucky Bluegrass to ammonium and nitrate ratios in the tissue (Nittler and Kenny 1977).

Various turfgrass researchers have used the solution culture method for conducting nutrient studies. The relative needs of the turf plant are easily determined when nutrient solution cultures are used (Knoop 1972). He found that plants supplied with optimum levels of all nutrients contained 2.8 percent N, 0.19 percent P, and 1.17 percent K.

Aesthetic values of Tifgreen bermudagrass were correlated with percent composition of N, P, and K in the tissues (Menn and McBee 1970). Deficiency symptoms for N appeared when the tissue content dropped below 2.25 percent, thinning of the foliage became noticeable when the K levels dropped below 1.8 percent, while a reduction in growth was evident when the P levels fell below 0.2 percent in the foliage.

Field tests indicate that forage grasses have similar nutritional requirements to turfgrasses. Optimum P content for coastal bermudagrass has been found to fall in the range of 0.15 to 0.20 percent (Woodhouse 1969). Jordan, Evans, and Rouse (1966), studied the response of coastal bermudagrass to applications of P and K as related to P and K levels in the soil. A chemical analysis of the plant material indicated that maximum yield was obtained when the forage contained about 0.16 percent P and 1.0 percent K on a dry weight basis. Percentage composition dropped as low as 0.1 percent P and 0.4 percent K on severely depleted plots. Levels of K at 2.0 percent or higher indicated luxury consumption. It was earlier concluded that the ideal fertilizer ratio should consist of one unit of P_2O_5 and two units of K_2O for each four units of nitrogen for good hay production (Jackson, Walker, and Carter 1959). This ratio is also believed to be optimal for good turf production (Beard 1973). Other ratios (4-1-1 or 3-1-2) may also be satisfactory.

N concentration below 2.50 percent are considered deficient while levels above 4.5 percent are considered excessive and could lead to an imbalance of other nutrients. Phosphorus is considered to be adequate at 0.3 percent but a response in terms of growth can be obtained at

0.6 percent or higher. Optimum K levels in leaf tissue of turfgrasses range from 1.5 to 2.5 percent (Duble 1977a).

The balancing of the nutrient ratio is important in that imbalances may cause deficiencies or excesses of other nutrients. Moberg *et al.* (1972) found that K added to a bentgrass green increased the K in the clippings and decreased the N, Ca, Mg, Mn, and Na. Excessive P levels have been shown to cause deficiencies of other nutrients in turfgrass, particularly iron (Duble 1977b).

Pellet and Roberts (1963) found that a high N level supplied to bluegrass in solution culture, resulted in an increase in the percentage of P and K in the clippings. Markland and Roberts(1969) also found that high levels of applied N caused an increase in potassium content of the foliage.

Greenhouse Environment vs Field Environment

There is some difference of opinion expressed in the literature as to whether critical concentrations determined in the greenhouse and in nutrient cultures are valid for use in the field. It is certainly easier to determine such values in the greenhouse if they are valid.

Lundegardh (1951) found the same critical concentrations in pot experiments as in the field. He found some effect of soil moisture tension on the critical N concentration in oats, but not in timothy (*Phleum pratense*), and not for P and K with either crop. Bould (1964) found that for several species, sand cultures gave the same critical concentrations as field experiments. Ulrich and Hills (1967) suggested that critical concentrations can be determined in solution, soil culture, or field experiments. However, Ulrich (1964) found that critical concentrations of NO_3 determined from soil experiments were as a rule much lower than from solution culture experiments. Joham (1951) found different critical concentrations for cotton in the field than in sand cultures in the greenhouse. Clements (1964) concluded that critical concentrations should be determined in the field. Proebsting and Brown (1954), and McKenzie (1967) suggested that critical values determined in one area may not be valid in another. This would presumably rule out greenhouse values as well. Smith (1967) mentioned the use of greenhouse data but concluded that critical values should finally be tested in the field.

From the information available it appears that critical concentrations determined in the greenhouse may on occasion be satisfactory for use in the field. However, there is sufficient evidence and opinion to the contrary, that this cannot be taken for granted.

CHAPTER III

Materials and Methods

Experiment I: Glasshouse Single Nutrient Treatments

Experiment I was conducted at the Pope Laboratory Glasshouse Facility at the University of Hawaii, Manoa Campus, Honolulu, Hawaii. The average day temperature in the glasshouse ranged from 30° to 35° C; the night temperature, from 20° to 22° C.

Stolons, 5 to 8 cm in length, were removed from existing pure stands of Tifdwarf bermudagrass and washed throroughly. After all decayed plant material and soil were removed, a major portion of the root system was eliminated by clipping. The 81 polyethylene pots in which the stolons were propagated were 20 cm in diameter and 25 cm deep. The pots were filled with pure quartz sand (Black Hawk flint shot, grade 3.0), which had been washed with 30% hydrochloric acid. The sand served as the growing medium throughout the present experiment.

To insure good rooting and to keep salts leached, water was applied in excess of the estimated consumptive use of 5 cm a week. To prevent drought, turf pots were irrigated by flooding. Deionized water was used throughout the present experiment. Once rooting ensued, full-strength Hoagland solution II (Arnon and Hoagland 1951), with 5 ppm of iron (Fe) as Sequestrene 330 and the usual essential micronutrient concentrations for favorable growth, was applied to each turf pot in 500 ml portions, enough solution to result in drainage. Soon after emergence, the turf pots were clipped with electric grass shears at a height of approximately 0.5 cm. Thereafter, all turf pots were clipped at weekly intervals, regardless of growth rates, at the 0.5 cm height.

After 2 months when the turf was fully established, treatments, listed in Table 1, were applied. There were 9 individual treatments of N, P, and K, respectively. A solution containing essential nutrients to constitute a standard Hoagland's solution (Arnon and Hoagland 1951), but lacking the nutrient under study (N, P, or K), was applied to all pots at a constant rate and in sufficient quantity to eliminate all other nutrients as limiting factors and variables. The source of N was NH_4NO_3; for P, $Ca(H_2PO_4)$; and, for K, K_2SO_4. All treatments were replicated 3 times in a randomized complete block design. Treatment solutions were applied on Monday, Wednesday, and Friday in 500 ml portions. Every Sunday, the pots were flushed with deionized water and drained for a period of 24 hours (hr). The solutions were checked periodically and maintained at a pH of 6.3 ± 0.2 with 1 N NaOH or 1 N H_2SO_4. Solutions were prepared as needed and the polyurethane carboys, which served as solution receptacles, were washed and rinsed thoroughly between changes. The treatment schedule was followed for 4 months, after which time the turfgrass manifested a definite gradation in symptoms from severe to no nutritional deficiency. Experimental data were then collected on a weekly basis for 4 consecutive weeks.

Visual ratings (VR) of turfgrass quality of individual turf pots served as a means of evaluating turfgrass responses to treatments. Since turfgrasses are grown more for aesthetic purposes, yields are not considered to be important methods for measuring turf quality. Although visual ratings are strictly subjective, many turfgrass researchers have used visual ratings as means of estimating turfgrass quality. Among the many were Horn (1965) and Menn and McBee (1970) in evaluating fertility trials on Tifgreen bermudagrass, Mantell and Stanhill (1966) in evaluating Nitrogen and irrigation frequency on Kikuyugrass, and a wide variety of fertility trials on Kentucky bluegrass (Juska and Hanson 1967, Kind and Skogley 1969, Ledeboer and Skogley 1973, and Wilkinson 1977). A single overall rating was made for each turf pot with the following characters taken into consideration: general appearance, color, uniformity, texture, density, and extent of deficiency symptoms, if any. The rating scale varied from 1 for the poorest of these characters to 5 for luxuriant turf. A score of 3 was taken to represent "acceptable" turf quality. To avoid personal bias, treatment conditions of turf pots were not made known to the rater during the rating process.

Dried weights of turf clippings (DW) were determined as a means of measuring growth response to treatments. The harvesting of turf clippings were facilitated with the use of a vacuum with a modified suction nozzle; a removable fine mesh collecting screen was affixed to the nozzle to prevent clipping loss and to hasten the collection process. Clippings from each turf pot were placed in individual brown paper bags and dried in a forced-draft oven at 60° C. After 24 hr of drying, individual DW were determined using a Mettler P1200 balance.

Chlorophyll content (CC) was extracted from the turf clippings using the method described in detail by Johnson (1974). Briefly, 20 mg of DW subsamples were immersed in 20 ml for 22-24hr. Optical density (OD) readings were then taken from a Unicam spectrophotometer at 650 nm and 665 nm, respectively. Using Johnson's formula, $(25.6 \times OD_{650} + 4.0 \times OD_{665})/DW_{subsample}$ (do not divide), relative CC data were calculated. The remaining dried clippings were then ground in a Wiley mill to pass a

30-mesh screen to be used for subsequent N, P, and K chemical analyses.

To determine nutrient uptake responses to treatments, ground clippings were chemically analyzed for percent (%) composition of N, P, and K, respectively. For %N and %P analyses, a tissue digestion procedure, essentially a combination of those described by Van Lieprop (1976) and Cataldo, Schrader, and Youngs 1974 (1976), was employed; this modified micro-Kjeldahl procedure entailed use of a H_2SO_4 digestion mixture (Schuman, Stanley, and Knudsen 1973), an aluminum heating block, and Folin-Wu digestion tubes. To obtain total %N readings, a colorimetric procedure described by Cataldo et al. (1976) was used. Total %P content was determined with use of the molybdenum blue method of Dickman and Bray, which is described in detail by Chapman and Pratt (1961). The determination of %K content did not entail digestion; instead, K was extracted from ground clippings in 50 ml test tubes by water immersion. The tubes were shaken in a horizontal position on a reciprocating mechanical shaker for 3 hr. Extractions were then filtered through Whatman No. 2 filter paper. Percent transmittance readings were taken at 768 nm on a Beckman Model B spectrophotometer, equipped with a flame attachment; readings were sequentially converted to ppm and %K, using KCl as the internal standard.

Experiment II: Outdoor Environment Studies

Experiment II was conducted in the field in order to evaluate the generalizability of results obtained under glasshouse conditions. At the conclusion of Experiment I, all 81 turf pots were transferred to the Plant Science Complex at the University of Hawaii, Mauka Manoa Campus, Honolulu, Hawaii and subjected to field conditions. The average outdoor day temperature ranged from 65° to 85° C; the night temperature, from 65° to 75° C. The average rainfall was 5.17 inches from October 1978 to May 1979.

Full-strength Hoagland solution II, cited in Experiment I, was applied to all turf pots in 500 ml portions. Uniform turf appearance across all turf pots was attained in 6 weeks, after which time treatments identical to those in Experiment I (Table I) were applied after re-randomizing the pots. To control for fungal and insect problems, pesticides were applied as needed. When a range of deficiency symptoms was manifested, after 2 months for N treatments, 8 for P, and 6 for K, VR were made and clippings were collected. Laboratory analyses of the clippings for DW, CC, and elemental composition of N, P, and K, respectively, were conducted, using the procedures described in Experiment I. Experimental data were collected on a weekly basis for 4 consecutive weeks.

Experiment III: Combination Treatments in Glasshouse

Experiment III was conducted to determine turfgrass responses to differential N, P, and K combination treatments. At the conclusion of Experiment II, 27 K treatment turf pots were transferred back to the glasshouse. As in Experiment II, Hoagland solution II was applied to all turf pots in 500 ml portions; uniform appearance across all turf pots was attained in 1 month. N, P, and K levels to be used in the present experiment were chosen for "acceptable" turf responses obtained in Experiments I and II. A modified Hoagland's solution, cited in Experiment I, but lacking P and K and with N level held at 125 ppm, was applied to all turf pots. The treatments consisted of varying levels

Table 1

Treatment Levels for N, P and K in ppm

	N Levels	P Levels	K Levels
1	6.25	0	0
2	12.50	4.0	6.25
3	25.00	8.0	12.50
4	50.00	12.0	25.00
5	75.00	16.0	50.00
6	100.00	20.0	75.00
7	125.00	24.0	100.00
8	150.00	28.0	125.00
9	175.00	32.0	150.00

Table 2

Combination Treatment Levels in ppm

N	P	K
125	4	50
	8	75
	12	100

of P and K in combination; the levels of P were 4, 8, and 12 ppm; for K, 50, 75, 100 ppm (Table 2). The resulting 9 treatments (3 X 3 factorial) were replicated 3 times in a randomized complete block design. A range of deficiency symptoms was manifested after 4 months. The turf pots were then subjected to VR and clippings were harvested. Laboratory analyses of the clippings were performed for DW, CC, and elemental composition of N, P, and K, respectively, using the procedures described in Experiment I. Experimental data were collected on a weekly basis for 4 consecutive weeks.

Field Monitoring Studies

Field monitoring studies were studies were conducted on Tifdwarf bermudagrass putting greens at the Waialae Country Club and the Oahu Country Club, both in Honolulu, Hawaii.

Using the scale described in Experiment I, VR were made on 4 putting greens (Nos. 11, 13, 14, and 15), 3 times a week, from January 3 to February 2, 1979 for a total of 13 dates. At the same time that VR data were obtained, a handful of turf clippings were retrieved from the collecting attachment of a triplex greens mower for each green under study. CC and elemental analyses for N, P, and K composition were determined using the procedures described in Experiment I. Monitoring visits were resumed between March 7 and April 15, 1979, again on a 3 times a week basis, resulting in collection of field study data for 15 dates.

Field study data on VR, CC, and elemental composition of N, P, and K were also obtained for 4 putting greens (Nos. 2, 6, 7, and 9) at the Oahu Country Club. Monitoring visits were made three times a week between January 17 and February 16, 1979, for a total of 13 dates, and between March 14 and April 13, 1979, for a total of 12 dates.

At both locations, greens were mowed to a height of 0.47 cm and irrigated daily to supply water to a depth of 2.5 to 5.0 cm in the root zone.

At Waialae Country Club, the greens were fertilized at a rate of 2 pounds N per 1000 sq ft every 2 weeks. Supplemental P and K were applied monthly.

At Oahu Country Club, the greens were fertilized every week at a rate of 0.5 pounds of N per 1000 sq ft. Supplemental P and K were included in the formulation.

Analysis of Data

For glasshouse and field single nutrient experiments, data on N, P, and K treatment effects on VR, DW, CC, and % composition of N, P, and K in turf leaf tissue were analyzed using analysis of variance (Anova) for a split-plot design with the N, P, or K levels arranged as a randomized complete block with three replicates (blocks). Parameter means were compared using Bayesian Least Significant Difference (BLSD) at the 5% level.

For glasshouse combination experiments, data were analyzed as a split-plot design with dates as main plots which included a 3 X 3 facotorial (P X K).

Statistical computation was aided with the use of the HP-2000 computer at the University of Hawaii Computer Center, Honolulu, Hawaii.

Seven different equations were obtained by the computer in plotting the response curve. These were:

1) $Y = A + B(X)$

2) $Y = A \cdot EXP(BX)$

3) $Y = A(X^B)$

4) $Y = A + (B/X)$

5) $Y = 1/(A + BX)$

6) $Y = X/(A + BX)$

7) $Y = A + B\ LOG(X)$

CHAPTER IV

Results

Experiment I: Glasshouse Single Nutrient Treatments

Nitrogen Treatments

Of N, P, and K, the effects of increasing fertility levels on VR of turf pots and DW, CC, and elemental composition of N in turf leaf tissue were most profound for N. Main N treatment effects are presented in Table 3 as mean values. For all six parameters, an increasing trend with increasing N levels was indicated, *i.e.*, higher N levels were in general associated with higher parameter values. Although some of the differences were not significant, mean values tended to increase with each increment of N level; broader differences were consistently observed for lower N levels, with the exception of %P which will be reported later. Correlation and regression analyses were performed on VR, DW, CC, and %N data; results are presented in Table 4. Resultant curvilinear graphs of positive functional relationships of N levels with individual parameters were, therefore, consistently negatively accelerated, *i.e.*, the slopes decrease as N levels increase.

VR effects. As expected, turf pots treated with low N levels ($\leq$ 25 ppm) were first to show evidence of N deficiency, yielding chlorotic, *i.e.*, pale green and then increasingly yellow, short, thin, and slightly necrotic leaf blades and reduced, slow growth; VR means ranged from 1.00 to 2.13. Conversely, high N levels ($\geq$ 100 ppm) resulted in richly green, fast-growing, succulent, and luxurious growth, with VR ranging from 4.42 to 4.67. Intermediate N levels of 50 and 75 ppm yielded turf of adequate or "acceptable" visual quality; VR were

3.04 and 4.04, respectively. Overall data for VR and N levels were significantly correlated ($r = 0.970$, $p < .01$). The response curve of VR plotted against N levels is presented in Figure 1. Three general zones are to be seen in this curve: (1) a zone of deficiency, with sharply increasing VR within a domain of 25 ppm, (2) transition zone, with less sharply increasing VR over a domain of approximately 50 ppm, and (3) a zone of adequacy, with increasingly constant VR over a broad domain of approximately 100 ppm. Differences of mean VR values were found to be significant (Anova, $p < .05$) between 6.25 and 25 ppm; this area corresponds to the zone of deficiency. Conversely, the area between 75 and 175 ppm corresponds to the zone of adequacy; significant differences between VR means were not obtained, with the exception of a mean value for 125 ppm of N.

DW effects. Turfgrass fertilized with higher rates of N produced greater amounts of DW clippings; DW and level of N were correlated at a significant level ($r = 0.970$, $p < .01$). Referring to Figure 2, the negatively accelerated curve begins to "level off"at 100 ppm of N. As would be expected, differences in DW for 100 ppm and greater were not found to be significantly different (Anova, $p > .05$), while mean DW values were significantly different at N levels of 25 ppm and less (Anova, $p < .05$). Thus, while the slope deceleration may have been gradual and the zone of adequacy not readily demarcated, a separation of low and high DW yields could be made.

CC effects. The correlation between CC and N levels was highly significant ($r = 0.972$, $p < .01$), resulting in the graph presented in Figure 3. Curve trends were similar to those reported for VR and DW;

"leveling off" for CC, however, began at a higher N level; mean difference analysis indicated that N level to be 125 ppm. For CC values for N levels 125 ppm and greater, no significant differences were obtained. Significant mean differences at the .05 level were obtained for all other N levels, with the exception of CC mean values for 6.25 and 12.5 ppm N.

%N effects. Results similar to those previously reported for VR, DW, and CC were obtained for the effects of increasing N levels on %N in leaf tissue. The observed trends of the response curve shown in Figure 4 were essentially identical to those for VR, DW, and CC data, with $r = 0.963$, $p < .01$. For all practical purposes, trends observed for VR mean differences were identical to those for %N. An increasing trend with increasing N levels was indicated up to the 75 ppm level of N, with "leveling off" occurring at and beyond 100 ppm. Mean %N difference analysis corresponded with these trends, as significant differences were obtained for means for 75 ppm and less (Anova, $p < .05$) and no significance was achieved by mean values for N levels 100 ppm and greater.

%P and %K effects. Supplementary Anova were performed on %P and %K data, resulting in significant differences between means for %K, but not for %P. Mean values for %K varied in essentially identical fashion to DW mean values.

Table 3

Effects of N Levels on Visual Ratings of Turf Pots and Dried Weights, Chlorophyll Content, and Percent Composition of N, P, and K, Respectively, of Leaf Tissue of Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

N Level	VR	DW	CC	%N	%P	%K
6.25	1.00 a	0.17 a	2.80 a	2.21 a	0.68	2.00 a
12.50	1.38 b	0.26 a	5.58 b	2.57 b	0.69	1.94 a
25.00	2.13 c	0.51 b	8.81 c	3.37 c	0.66	2.41 b
50.00	3.04 d	0.99 c	11.84 d	4.18 d	0.65	2.69 c
75.00	4.04 e	1.79 d	13.77 e	4.48 e	0.71	2.85 d
100.00	4.42 f	2.09 e	14.93 f	5.19 f	0.71	3.12 e
125.00	4.50 fg	2.04 e	15.83 g	5.19 f	0.69	3.16 e
150.00	4.38 f	2.06 e	15.90 g	5.25 fg	0.76	3.10 e
175.00	4.67 g	2.17 e	16.24 g	5.41 g	0.77	3.10 e
BLSD	0.19	0.14	0.64	0.19	---	0.10

For each column, means for treatments followed by the same letter do not differ significantly (BLSD = 0.05).

Table 4

Regression Equations and Correlation Coefficients Between the Evaluation Parameters and N Levels on Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

Comparison	Regression Equation	r
N Level(X) vs VR(Y)	Y = 1.497 + 1.214 LOG(X)	0.970**
N Level(X) vs DW(Y)	Y = -1.423 + 0.701 LOG(X)	0.920**
N Level(X) vs CC(Y)	Y = -4.807 + 4.209 LOG(X)	0.972**
N Level(X) vs %N(Y)	Y = 0.134 + 1.035 LOG(X)	0.963**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

Table 5

Regression Equations and Correlation Coefficients for Parameters Used for Evaluation of N Treatment Effects on Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

Comparison	Regression Equation	r
1) DW(X) vs VR(Y)	Y = 1.260 + 1.512 (X)	0.928**
2) CC(X) vs VR(Y)	Y = 0.043 + 0.275 (X)	0.953**
3) %N(X) vs VR(Y)	Y = -1.367 + 1.105 (X)	0.946**
4) %N(X) vs DW(Y)	Y = -1.293 + 0.625 (X)	0.869**
5) %N(X) vs CC(Y)	Y = -4.427 + 3.845 (X)	0.954**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

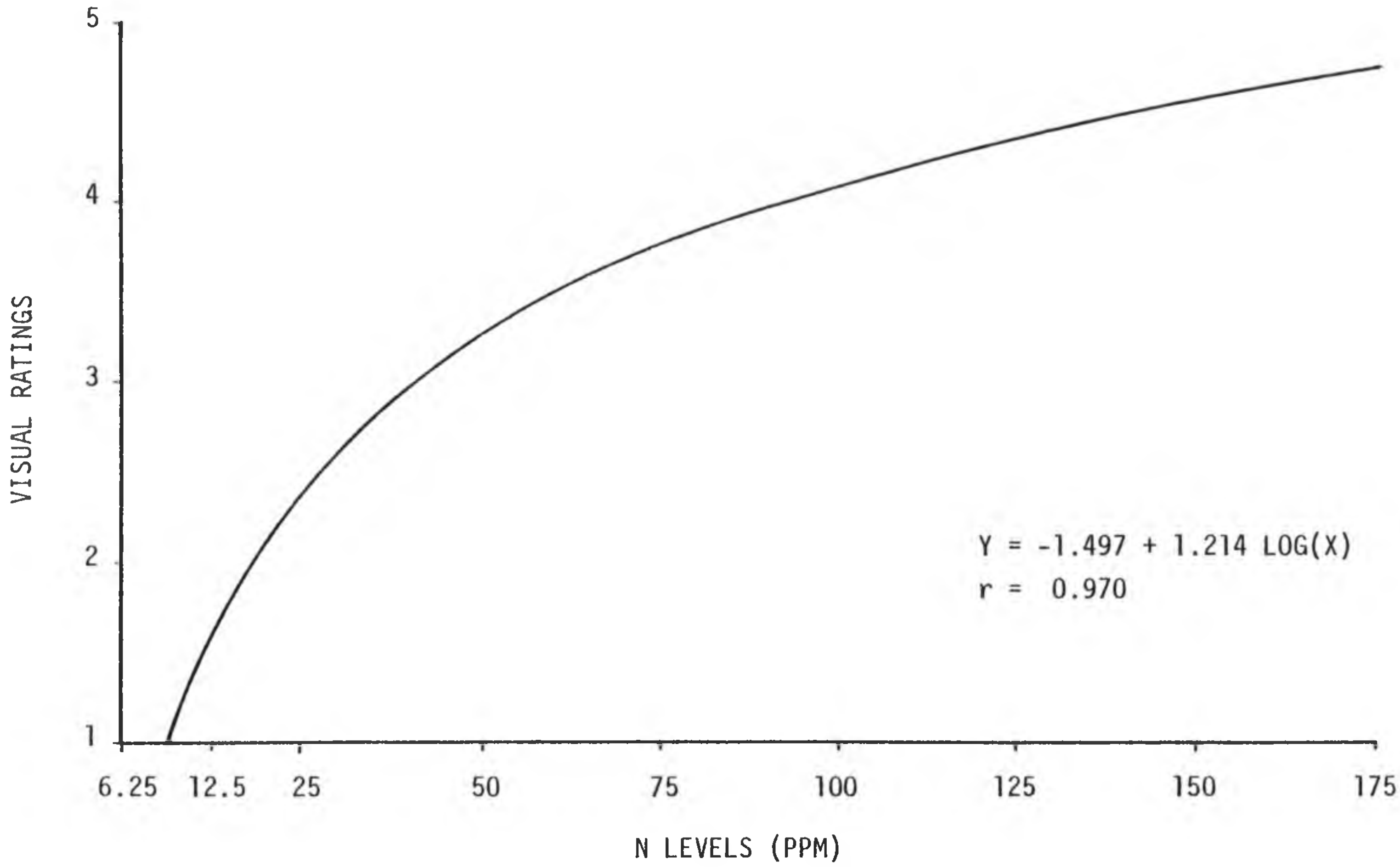

Figure 1. The effect of N levels on visual ratings.

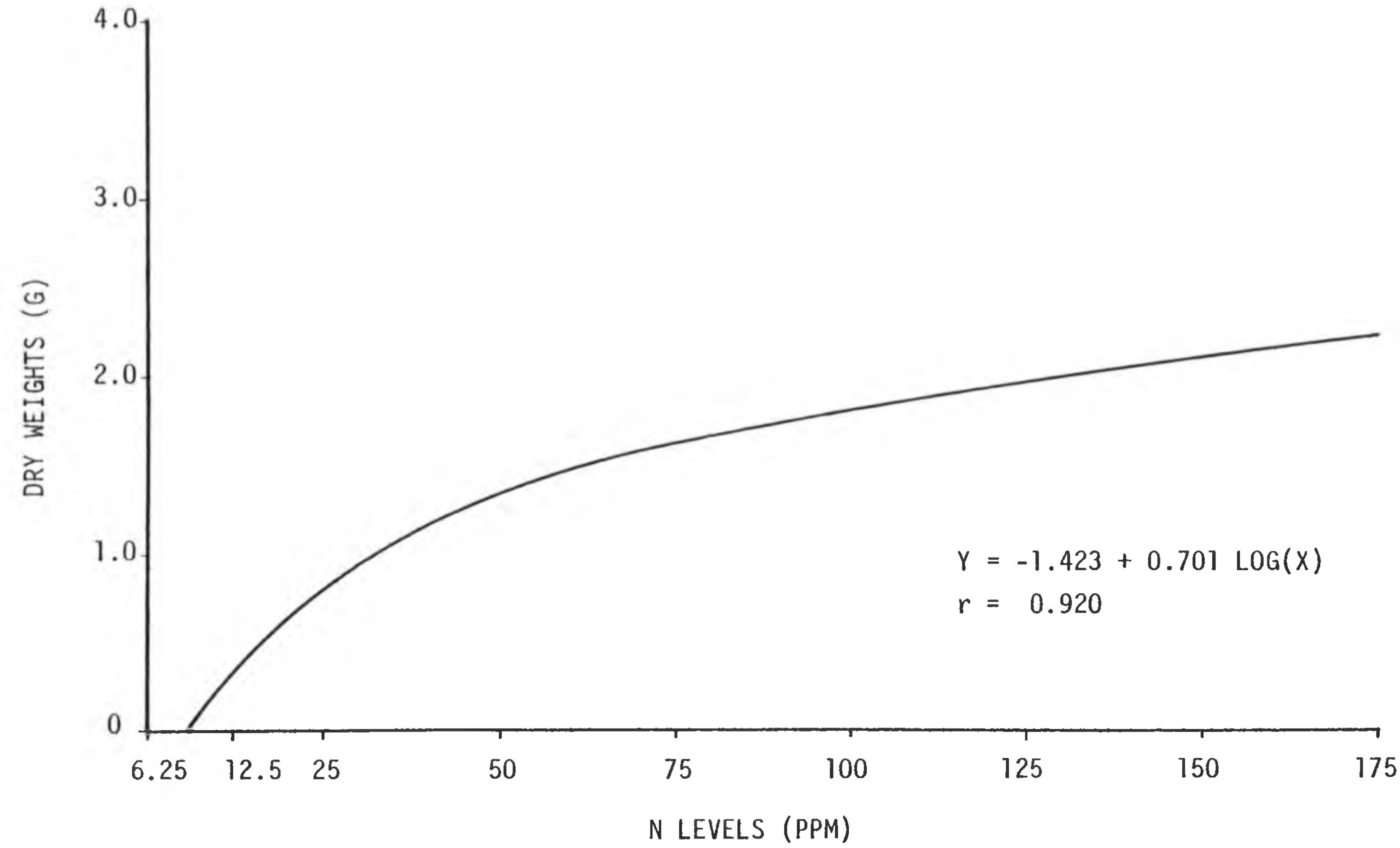

Figure 2. The effect of N levels on dry weight yields.

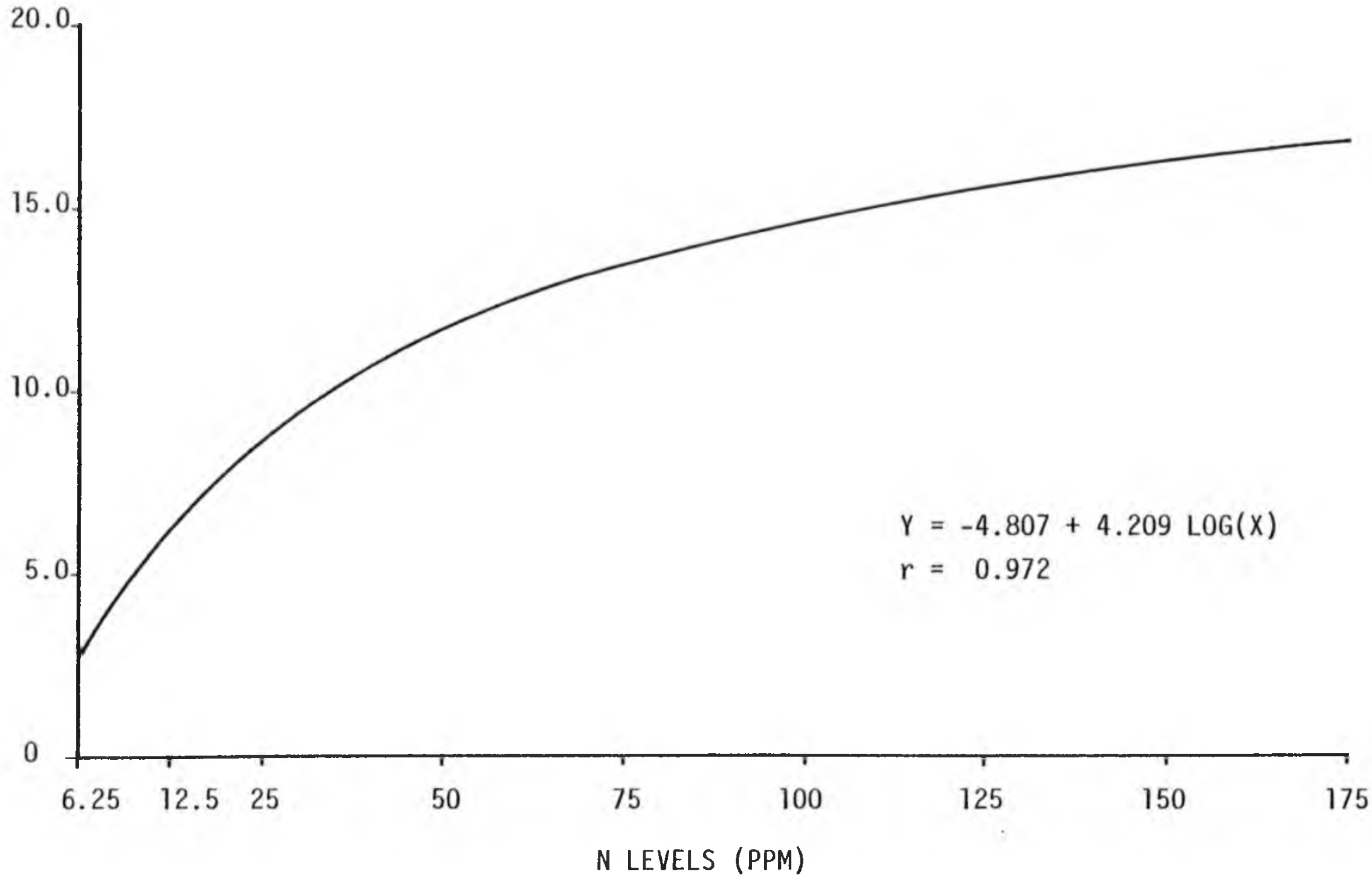

Figure 3. The effect of N levels on chlorophyll content.

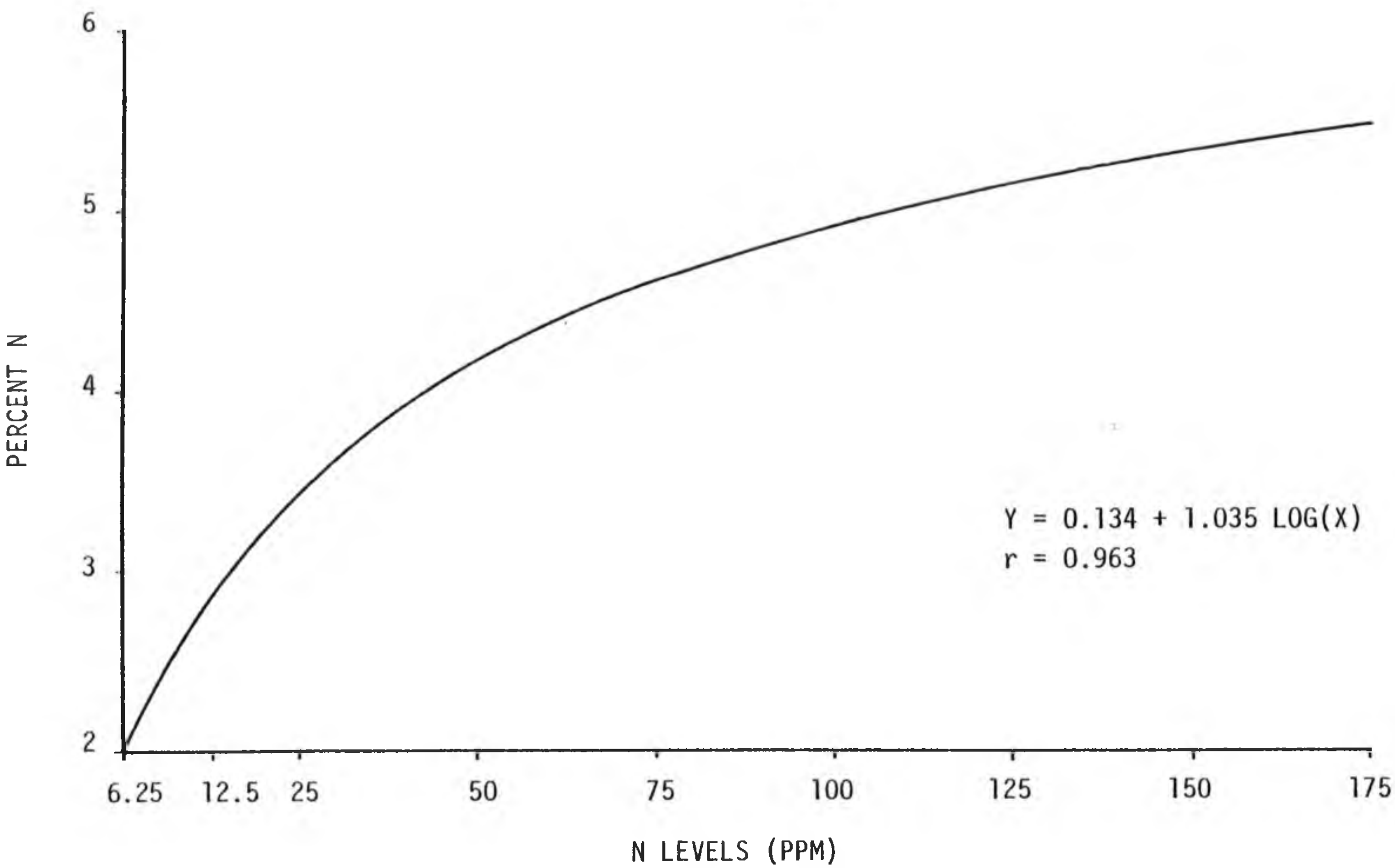

Figure 4. The effect of N levels on percent N in tissue.

Comparison of Parameters by Correlation and Regression

The primary parameters, VR, DW, CC, and %N, used in evaluating N treatment effects, were found to be significantly correlated one with another at the 1% level. Correlation coefficients and regression equations for the five comparisons are presented in Table 5. Graphical representations of the relationships were consistently linear with positive slopes; trends observed in one graph, therefore, can be expected to appear in another, given significantly high correlations (Figures 5 through 9).

Relative to other parameter comparisons involving VR, the correlation between DW and VR was the lowest ($r = 0.928$), albeit highly significant. Interpolation of the resultant regression graph in Figure 5 indicated that a DW of 1.15 g was associated with an "acceptable" turf quality rating (VR = 3). Increasing DW values in excess of 1.15 g reflected turf quality approaching luxuriance; decreasing DW values less than 1.15, on the other hand, reflected turf of poor quality.

CC compared with VR resulted in the second highest correlation value ($r = 0.953$). Figure 6 shows that an "acceptable" VR was associated with a CC of about 10 mg/g.

The comparison of %N with VR yielded an r value of 0.946 and an "acceptable" VR associated with a %N value of 4.0 (Figure 7).

The correlations of %N with VR, DW, and CC were consistently high ($r = 0.946$, $r = 0.869$, and $r = 0.954$, respectively. The correlation for %N with CC was the highest across all comparisons made. DW, correlated with %N, resulted in a low value relative to those of other comparisons.

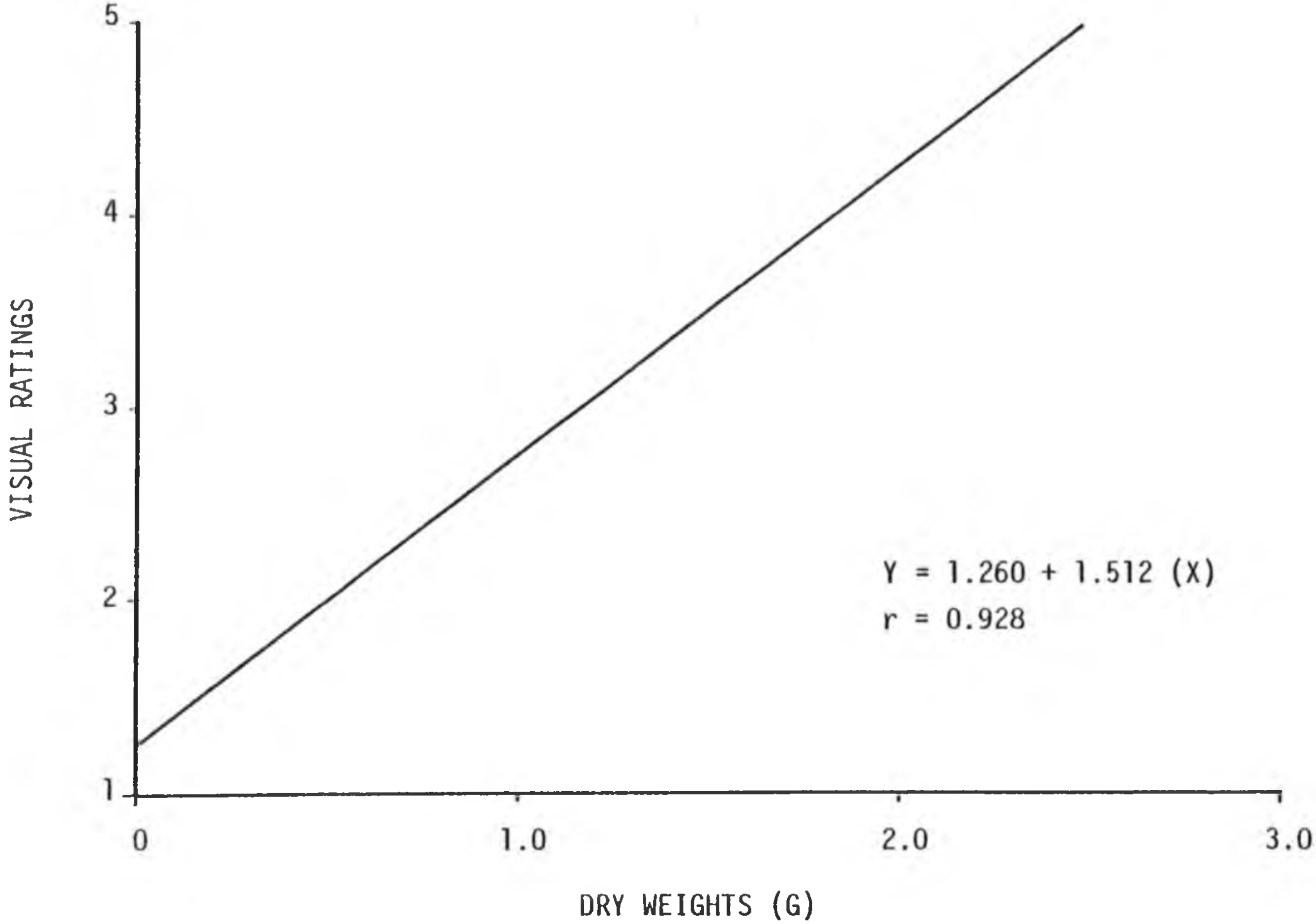

Figure 5. The relationship between visual ratings and dry weight yields.

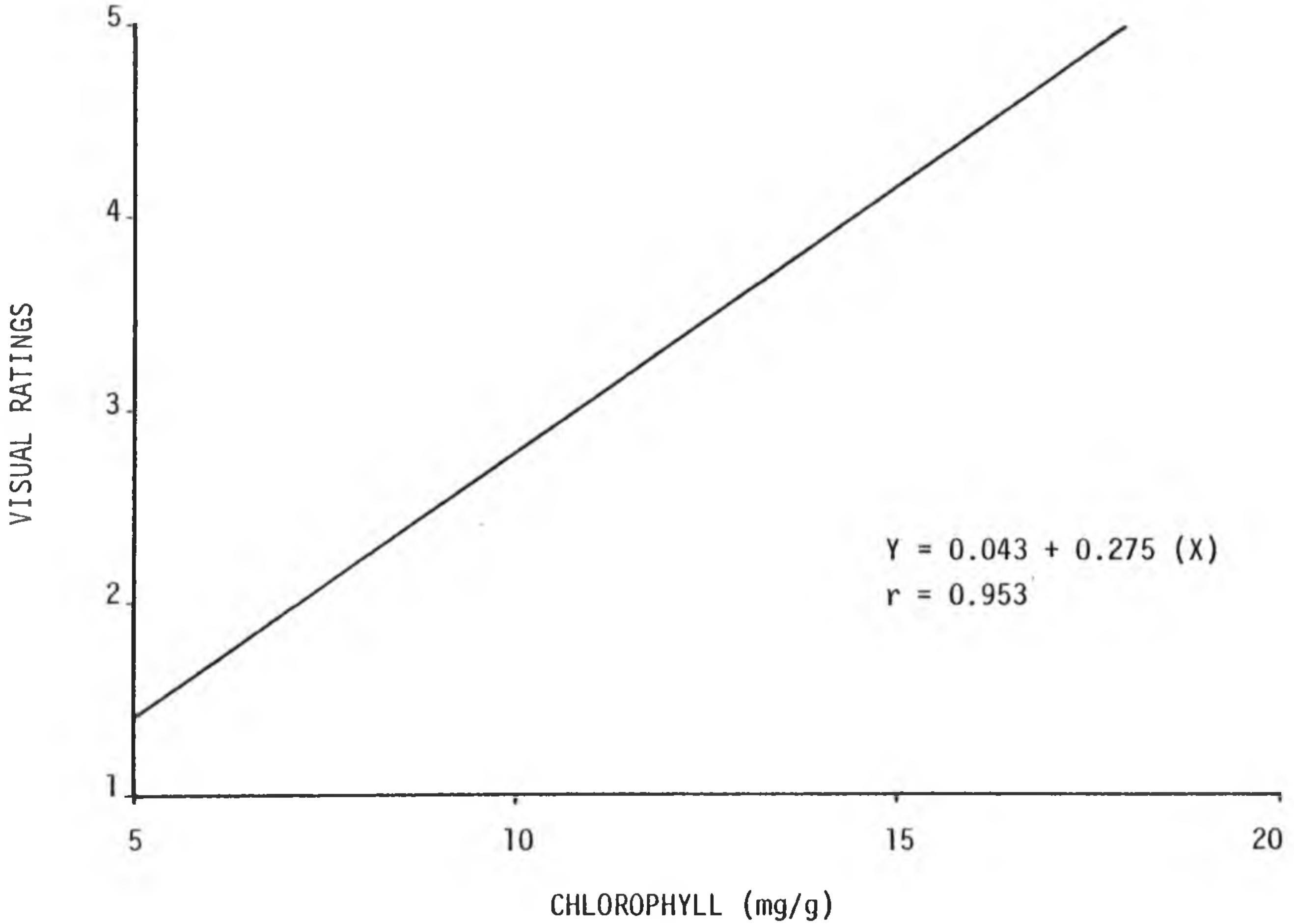

Figure 6. The relationship between visual ratings and chlorophyll content.

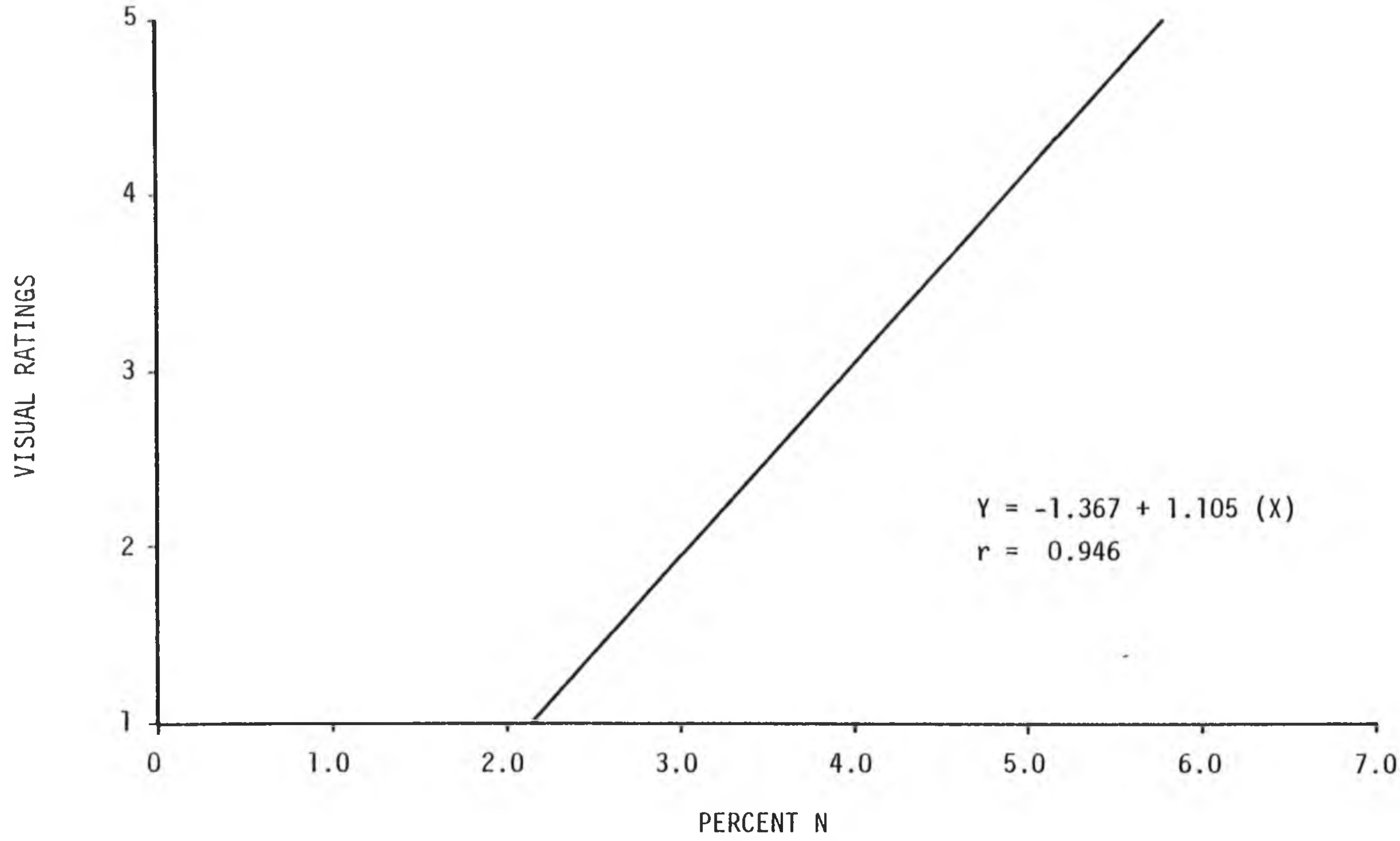

Figure 7. The effect of percent N on visual ratings.

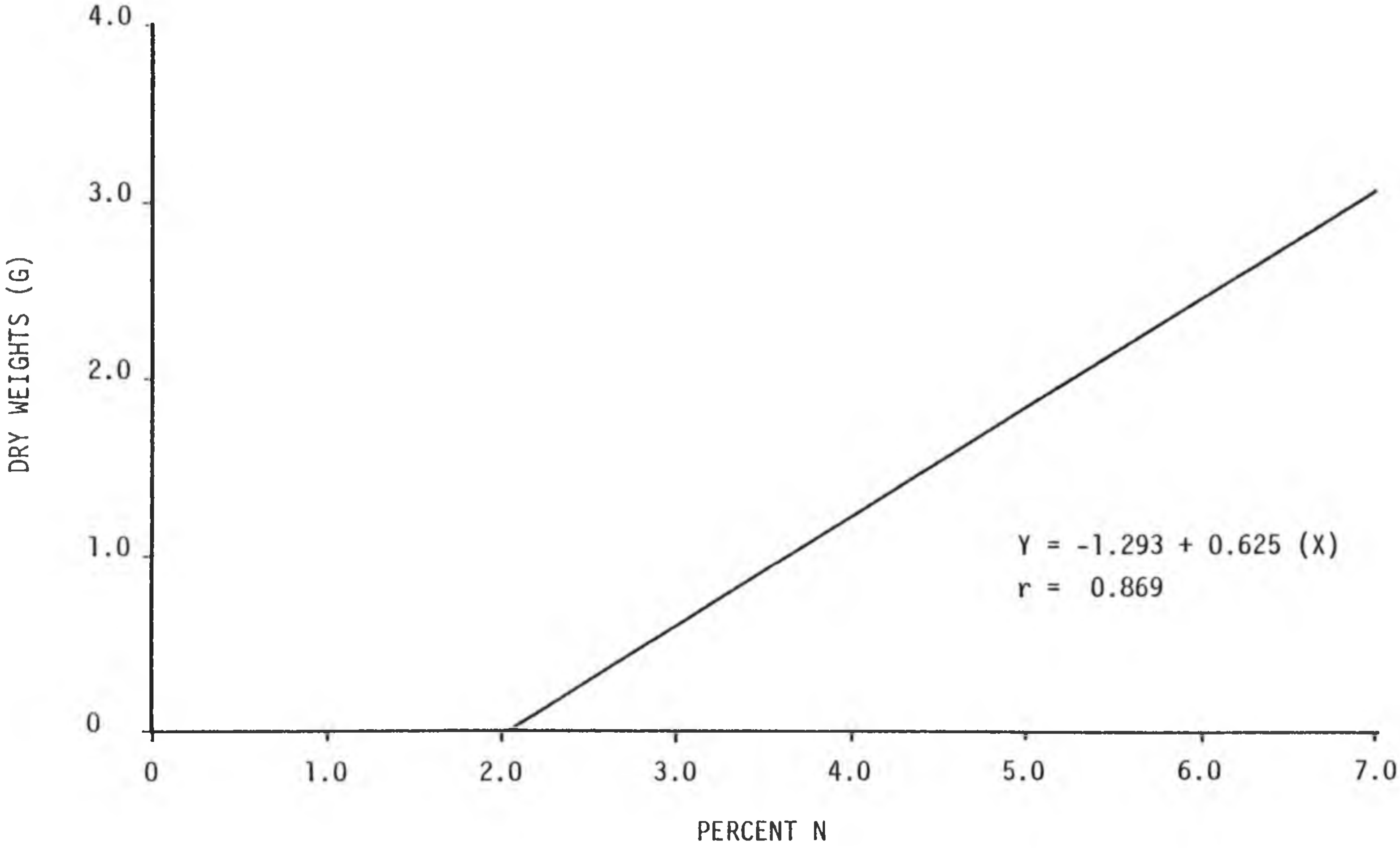

Figure 8. The effects of percent N on dry weight yields.

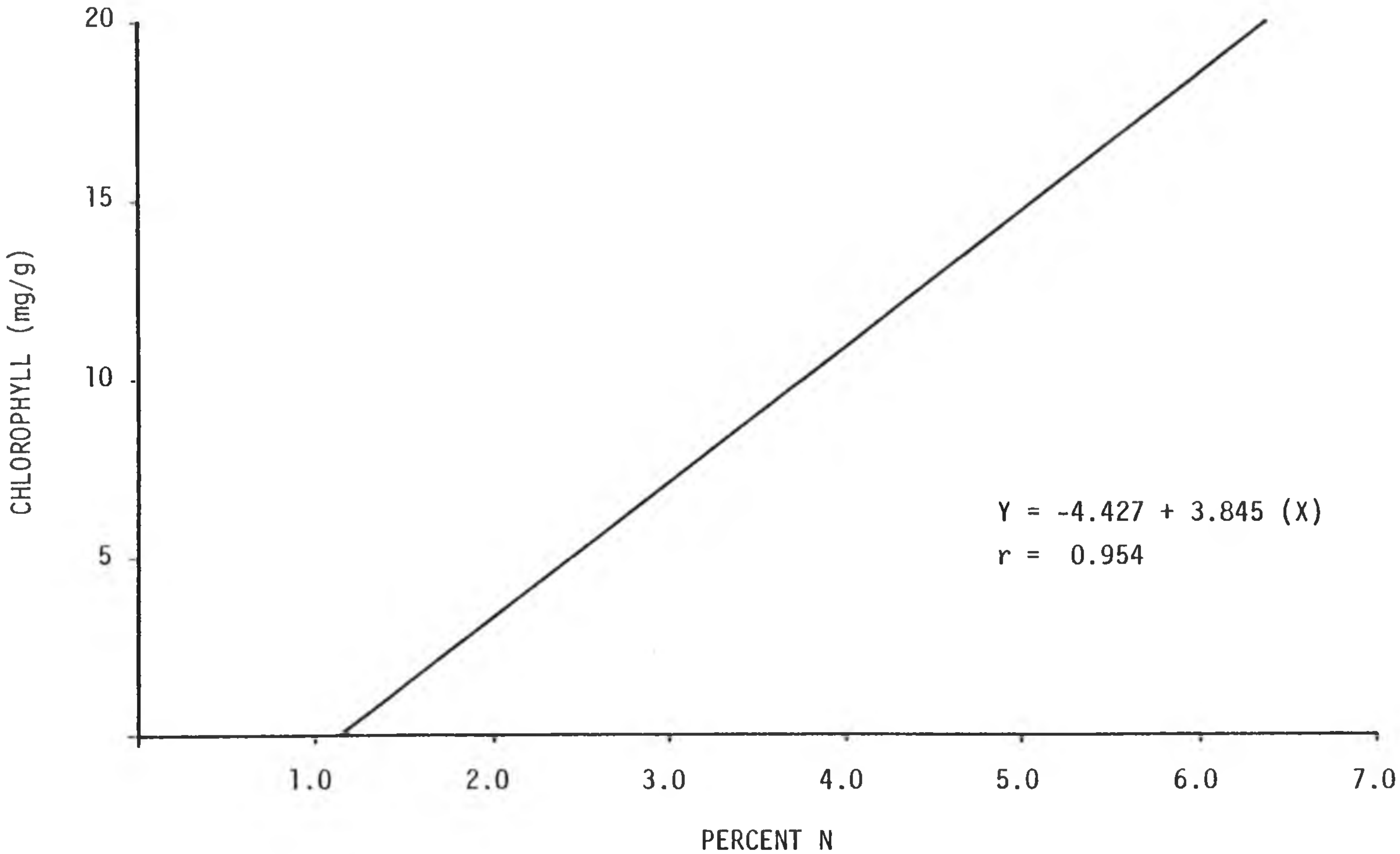

Figure 9. The effect of percent N on chlorophyll content.

Phosphorus Treatments

The effects of increasing P levels on VR, DW, CC, and the percent composition of N, P, and K are summarized as mean values in Table 6. Although some of the differences between mean values of these parameters were not significant, distinctly positive trends were apparent for VR, DW, CC, and %P. Mixed trends were noted for %N and %K mean values, as will be reported later. Broader differences were observed for lower P levels for those parameters displaying positive trends, while for higher P levels, treatment differences were smaller or even non-existent. Correlation and regression analyses were performed on VR, DW, CC, and %P data; results are tabulated in Table 7. Resultant curvilinear graphs of the positive relationships of P levels with parameter values were, not surprisingly, negatively accelerated.

VR effects. VR means ranged from 2.50 to 3.67; these extreme values were within $\pm$ 1.00 of the "acceptable" VR of 3. Profound deficiency symptoms, therefore, were not manifested, with slight yellowing for the 0 ppm P level being the only discernible symptom. The greatest increase in VR with increasing P fertilization occurred between 0 and 8 ppm; mean VR differences between P level increments were found to be significant (Anova, $p < .05$). For overall data analyses of VR, the correlation between VR and P level was found to be significant ($r = 0.383$, $p < .01$), although seemingly low. The curve of VR plotted against P levels is shown in Figure 10. Two distinct zones are to be seen in this curve: (1) a zone of transition, where VR increases within a domain of 8 ppm (between 0 and 8 ppm), and (2) a zone of adequacy with relatively constant VR over a broader domain of 24 ppm (between 8 and 32 ppm).

These curvilinear trends were consistent with results obtained by Anova, as discussed earlier. A zone of deficiency was not represented in the curve.

<u>DW effects</u>. DW mean values ranged from 0.56 to 1.12 g (Figure 11). Although a positive trend is discernible, increase of mean DW values with increments of P level was not consistent beyond 4 ppm P. As would be expected, the resulting overall correlation coefficient was 0. Nevertheless, the response curve did indicate trends similar to those obtained for VR data; in particular, the zones of transition and adequacy are easily demarcated at about the 4 ppm level.

<u>CC effects</u>. The range of CC mean values was 12.14 to 15.05. Similar to that indicated by DW data, an increasing trend by CC mean values with increasing P levels was apparent; this trend was observed only up to the 4 ppm level of P, with "leveling off" occurring beyond this level. The increase of CC mean value with increasing P levels, however, was not consistent for the higher P levels. These trends are clearly reflected from the response curve, although significance was not attained for the correlation between CC and P levels (Figure 12). Moreover, zones of transition and adequacy appeared to be demarcated at the 4 ppm level of P.

<u>%P effects</u>. Mean values of %P ranged from 0.25 to 0.68. Except for P levels at 24 and 28 ppm, increased P levels resulted in higher %P. More %P mean differences at significant levels (5%) were obtained for lower %P values than for those higher, using Anova. The correlation of P levels with %P in leaf tissue was significant ($r = 0.373$, $\underline{p} < .05$). Although the slope was less steep at the lower P level for %P (Figure 13),

the curve trends were similar to those of VR data (Figure 10), in particular; as in the VR curve, zones of transition and adequacy were relatively easily demarcated at the 8 ppm level of P (Figure 13).

%N and %K effects. Supplementary Anova were performed on mean values of %N and %K; significant differences between means were obtained for both parameters. As stated earlier, data trends were mixed and not consistent with those of the other parameters. For %N mean values, an increase followed by a decrease occurred with increasing P levels: %N mean values began to decrease at the 24 ppm P level. For %K mean values, an inverse trend was indicated by decreasing %N values with increasing levels of P.

Table 6

Effects of P Levels on Visual Ratings of Turf Pots and Dried Weights, Chlorophyll Content, and Percent Composition of N, P, and K, Respectively, of Leaf Tissue of Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

P Levels	VR	DW	CC	%N	%P	%K
0	2.50 a	0.56 a	12.14 a	4.17 a	0.29 a	2.99 b
4	3.17 b	1.06 cd	14.63 bcd	4.61 b	0.44 b	2.97 b
8	3.58 c	1.02 bcd	14.93 cd	4.83 cd	0.50 bc	2.96 b
12	3.67 cd	1.10 d	14.39 b	4.84 cd	0.57 cd	2.94 b
16	3.67 cd	0.98 bc	14.85 bcd	4.90 d	0.66 de	2.89 ab
20	3.75 d	1.12 d	15.05 d	4.82 cd	0.66 de	2.89 ab
24	3.67 cd	1.11 d	14.48 bc	4.58 b	0.55 c	2.90 ab
28	3.54 c	0.93 b	14.46 bc	4.70 bc	0.60 cde	2.78 a
32	3.67 cd	1.08 cd	14.99 d	4.70 bc	0.68 e	2.89 ab
BLSD	0.17	0.11	0.51	0.16	0.11	0.13

For each column, means for treatments followed by the same letter do not differ significantly (BLSD = 0.05).

Table 7

Regression Equations and Correlation Coefficients Between the Evaluation Parameters and P Levels on Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

Comparison	Regression Equation	r
P Level(X) vs VR(Y)	Y = 2.960 + 0.227 LOG(X)	0.383**
P Level(X) vs DW(Y)	Y = 1.059 - 0.005 LOG(X)	0 --
P Level(X) vs CC(Y)	Y = 14.063 + 0.215 LOG(X)	0.173--
P Level(X) vs %P(Y)	Y = 0.320 + 0.097 LOG(X)	0.373**

**Required r value for significance at the 1% level was 0.254 and at the 5% level was 0.195 with 106 degrees of freedom.

Table 8

Regression Equations and Correlation Coefficients for Parameters Used to Evaluate P Treatment Effects on Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

Comparison	Regression Equation	r
1) DW(X) vs VR(Y)	Y = 2.395 + 1.074 (X)	0.572**
2) CC(X) vs VR(Y)	Y = 0.547 + 0.203 (X)	0.479**
3) %P(X) vs VR(Y)	Y = 2.695 + 1.396 (X)	0.520**
4) %P(X) vs DW(Y)	Y = 0.874 + 0.218 (X)	0.514**
5) %P(X) vs CC(Y)	Y = 13.573 + 1.469 (X)	0.234*

*Required r value for significance at the 5% level was 0.195.
**Required r value for significance at the 1% level was 0.254.

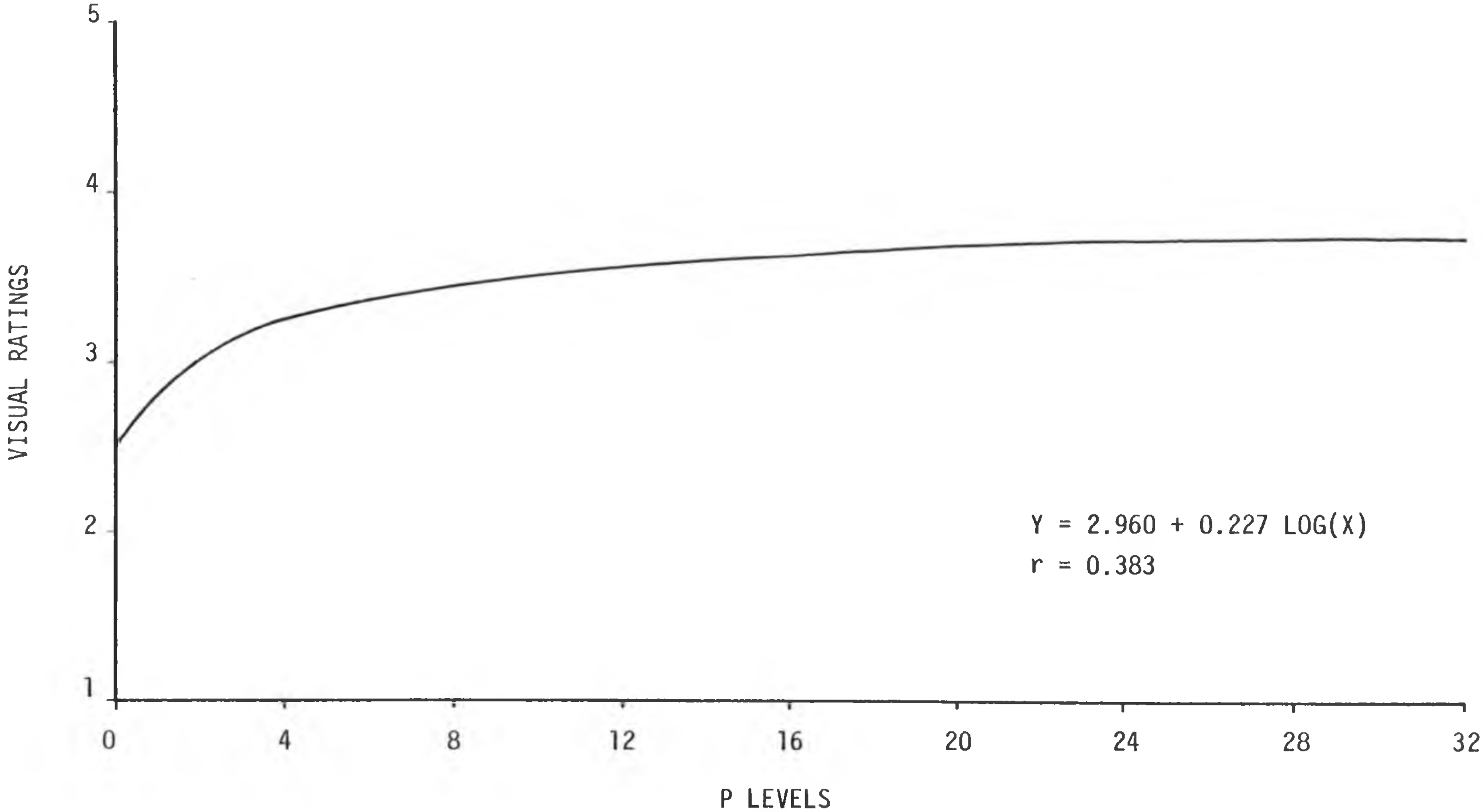

Figure 10. The effects of P levels on visual ratings.

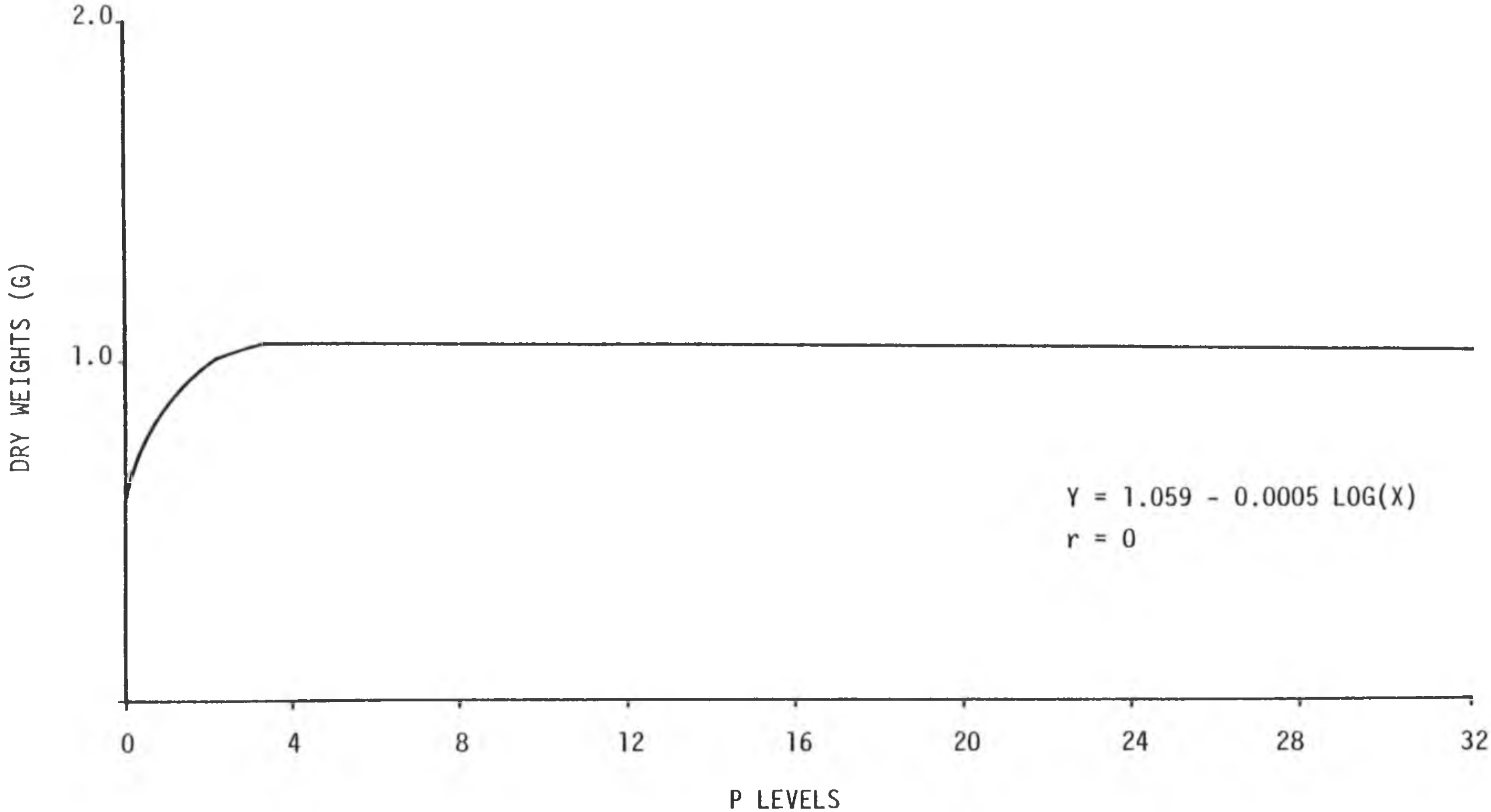

Figure 11. The effect of P levels on dry weight yields.

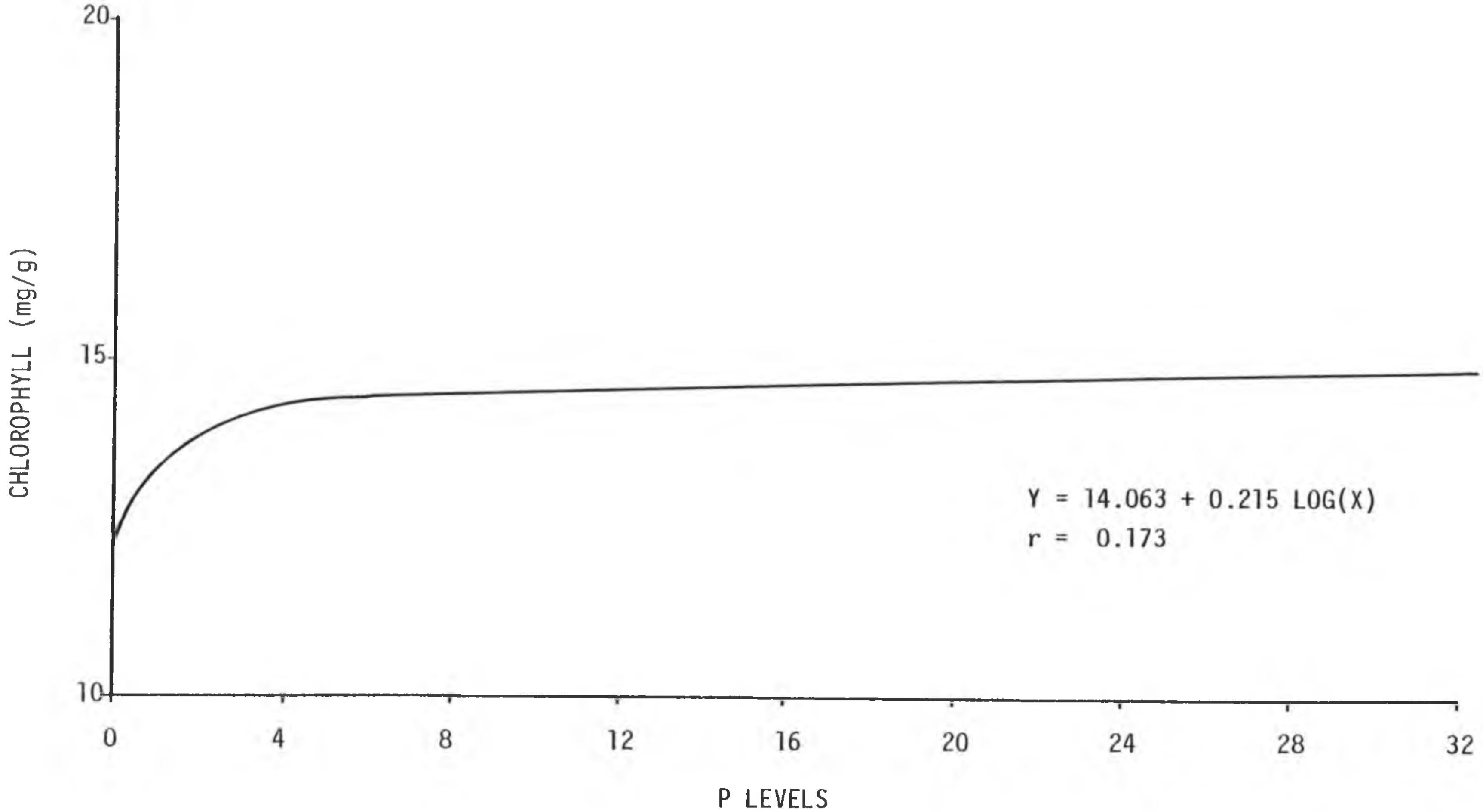

Figure 12. The effects of P levels on chlorophyll content.

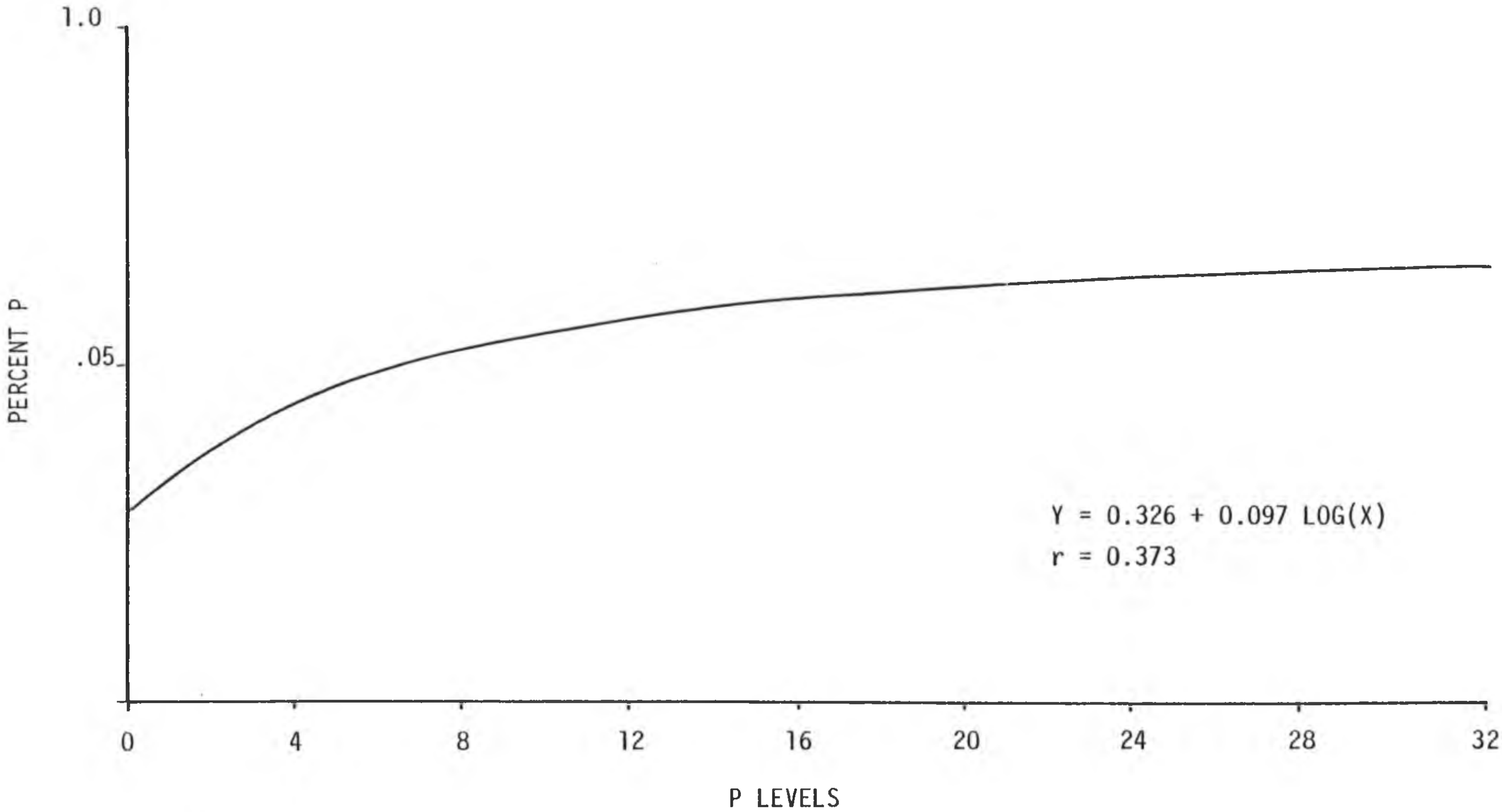

Figure 13. The effect of P levels on percent P in the tissue.

Comparison of Parameters by Correlation and Regression

The primary parameters, VR, DW, CC, and %P, used to evaluate P treatment effects were correlated one with the other. Correlation coefficients and regression equations are presented in Table 8. Except for the correlation of %P and CC which was significant at the 5% level, all other comparisons resulted in significant correlations at the 1% level. Graphical representations for all comparisons were linear with positive slopes (Figures 14 though 18).

The highest correlation for all comparisons were obtained for DW with VR ($r = 0.572$, $p < .01$). Interpolation of the resultant regression graph shown in Figure 14 indicated that a DW of about 0.5 g was associated with an "acceptable" VR of 3. Increasing DW values in excess of 0.5 g reflected turf quality approaching luxuriance, while decreasing DW values less than 0.5 g reflected turf of poor visual quality.

CC compared with VR resulted in an r value of 0.479, $p < .01$. Figure 15 shows that interpolation of the CC value associated with a VR of 3 was 12 mg/g.

The correlations of %P with VR, DW, and CC were all significant ($r = 0.520$, $p < .01$; $r = 0.514$, $p < .01$; and $r = 0.234$, $p < .05$, respectively). Of these the correlation of %P with VR was highest, while the correlation of %P with CC was lowest.

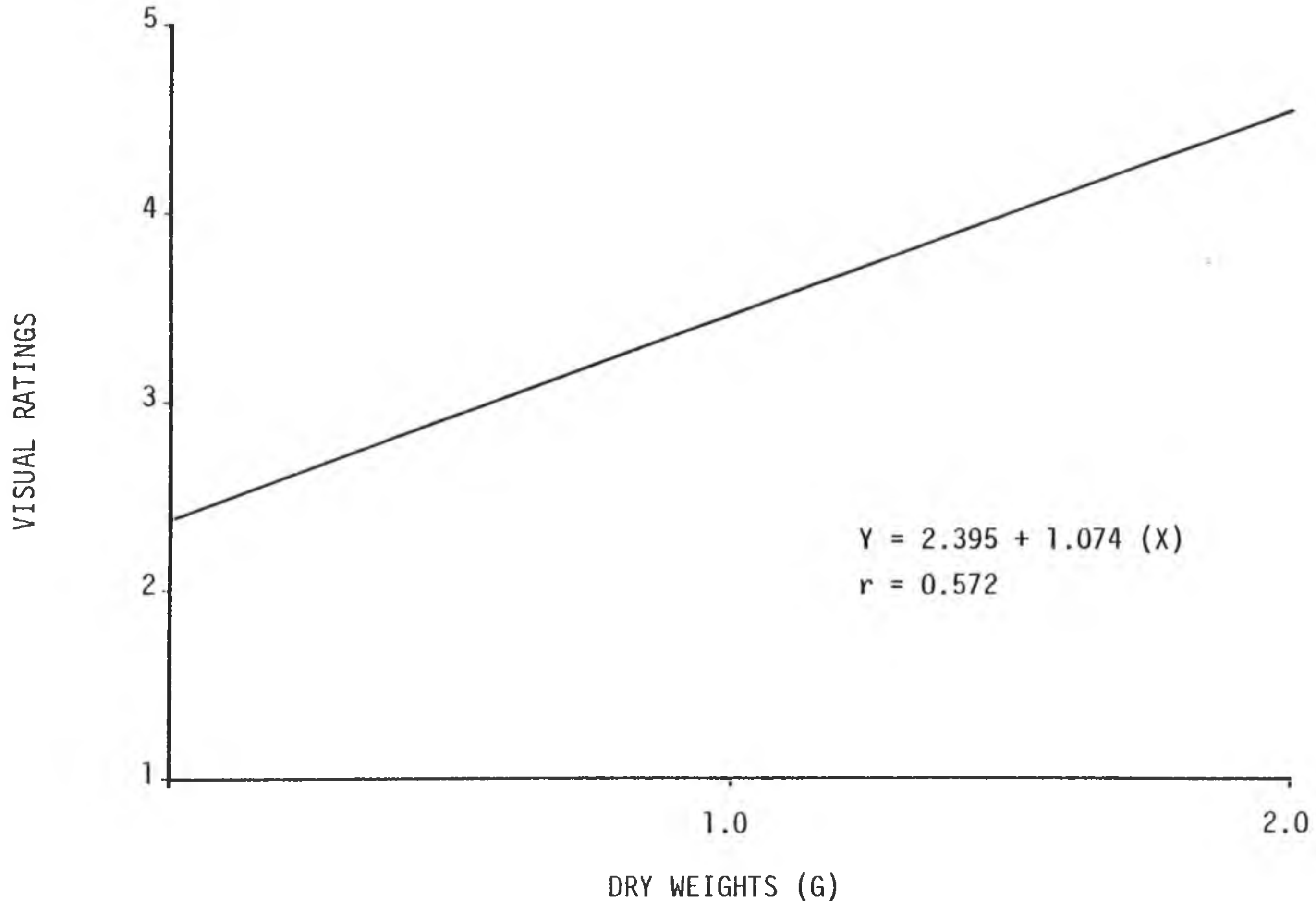

Figure 14. The relationship between visual ratings and dry weights.

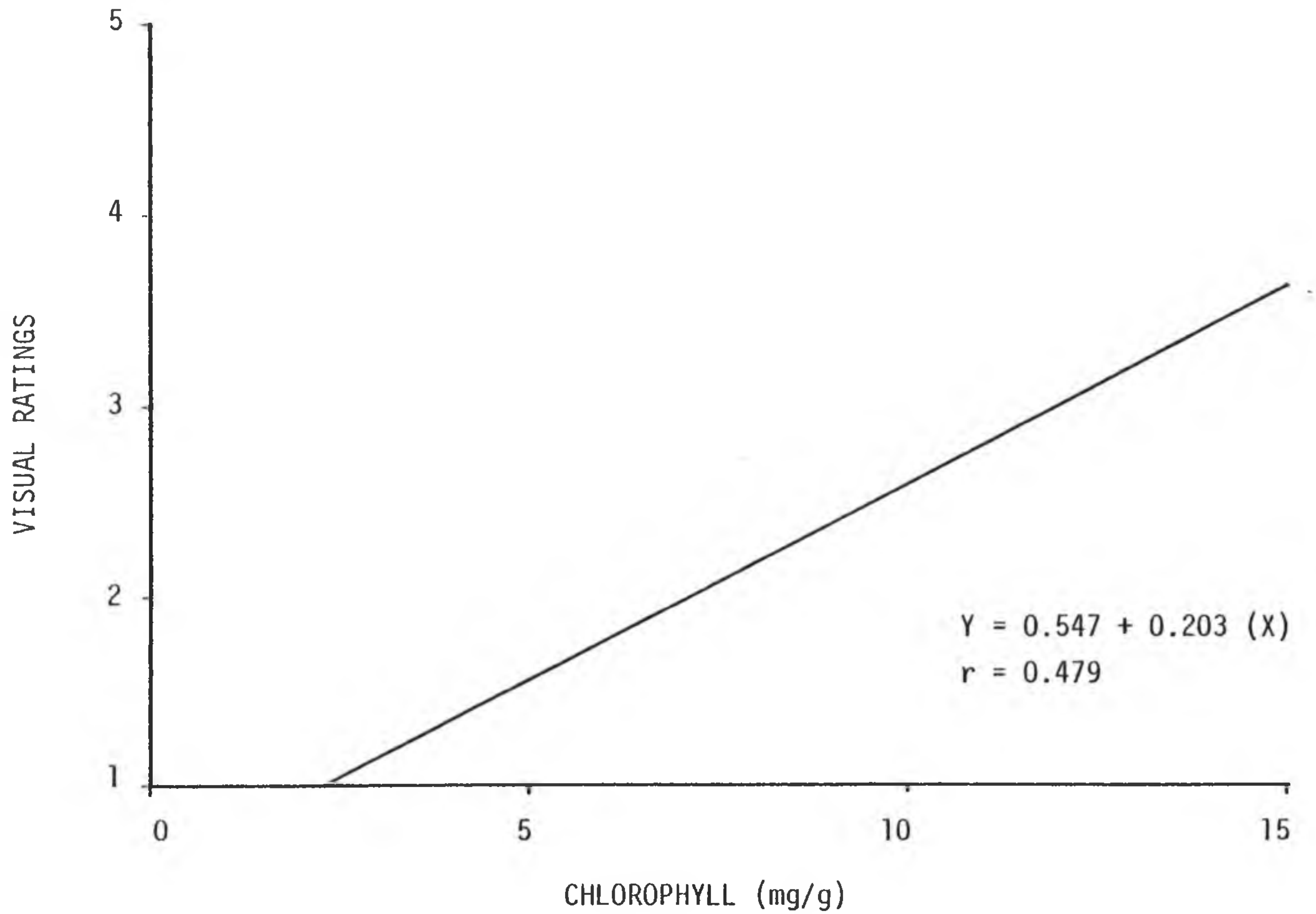

Figure 15. The relationship between visual ratings and chlorophyll content.

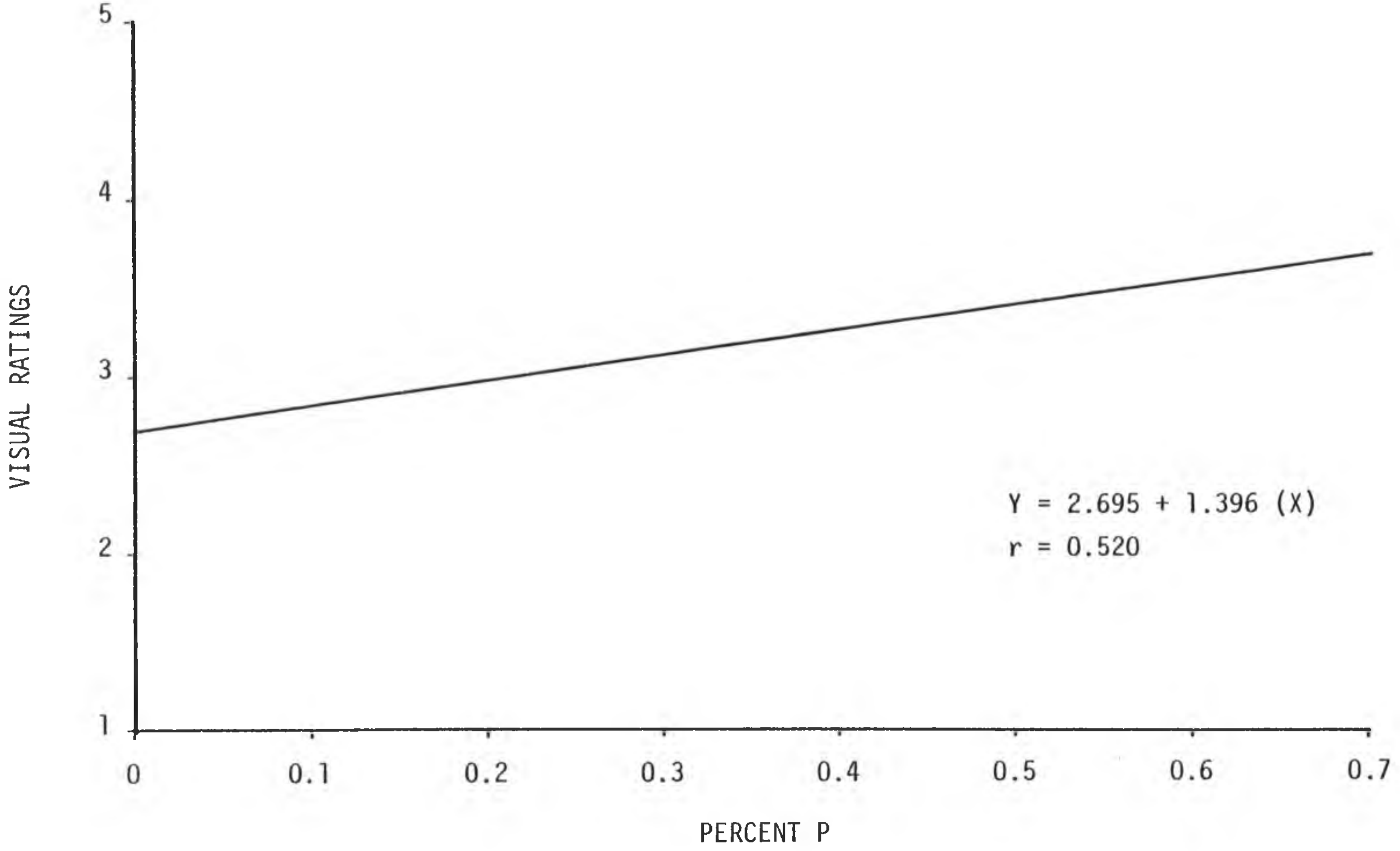

Figure 16. The effects of percent P on visual ratings.

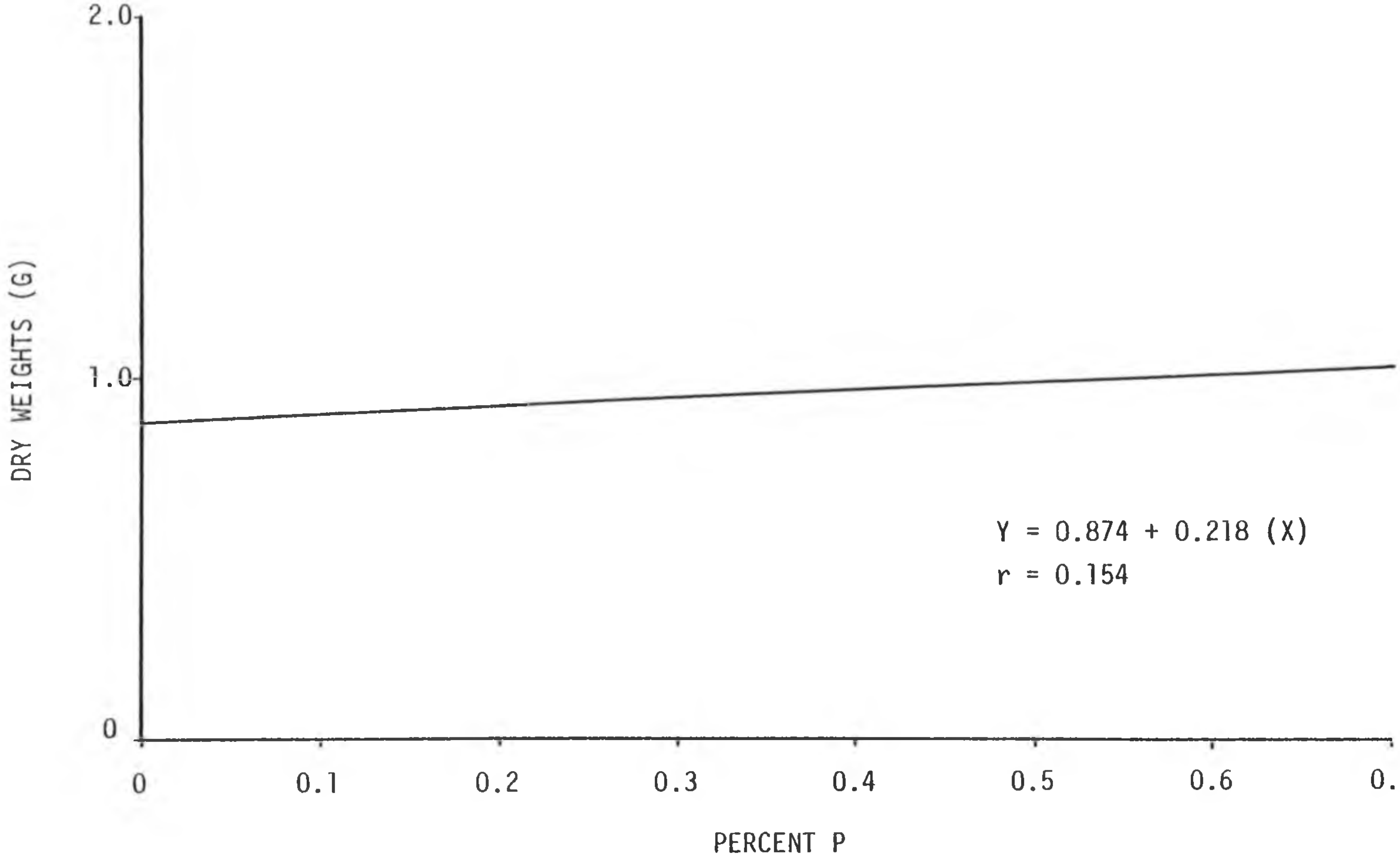

Figure 17. The effects of percent P on dry weight yields.

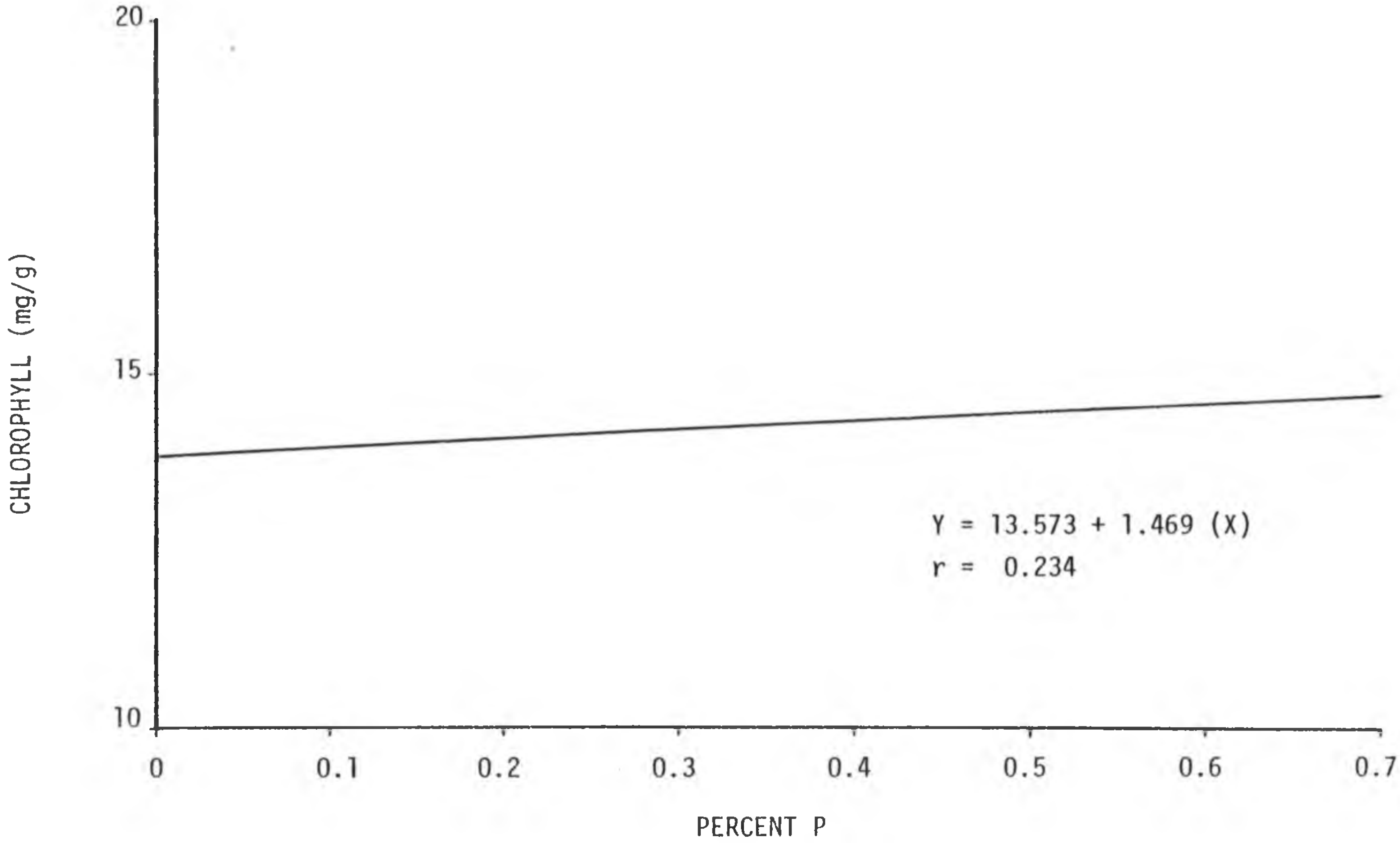

Figure 18. The effect of percent P on chlorophyll content.

Potassium Treatments

The effects of increasing levels of K on VR, DW, CC, and percent composition of N, P, and K are summarized as mean values in Table 9. For VR, DW, %N and %K, means for varying levels were not consistently significant; nevertheless, trends of increasing parameter values with increasing K levels were observed, with the exceptions being CC and %P. Correlation and regression analysis were performed on the data obtained for the primary parameters, VR, DW, CC, and %K, and tabulated results are presented in Table 10. Resultant response curve of the relationships of K levels were negatively accelerated.

VR effects. The VR means ranged from 2.04 to 3.96; these extreme values were approximately $\pm$ 1.00 of the "acceptable" VR of 3. Turf pots treated with the lowest K levels (0 and 6.25 ppm) manifested deficiency symptoms, which included narrow, pale green leaves, distinct thinning, tip necrosis, and reduced growth. An average VR of 3.38 was obtained at the 12.5 ppm K level and increased K levels from 50 to 150 ppm produced significantly higher VR. Overall data for VR and K levels were significantly correlated ($r = 0.603$, $p < .01$). The response curve of VR plotted against K levels is presented in Figure 19. A zone of deficiency was easily demarcated at the 6.25 level of K, followed by a zone of transition between 12.5 and 25 ppm, and a zone of adequacy beyond 25 ppm, respectively.

DW effects. DW mean values ranged from 0.63 to 1.23. Although a positive trend is perceptible at the lowest K levels, the increase of mean DW values with increasing K levels was not consistent. The resulting overall correlation coefficient was not significant ($r = 0.095$,

$p > .01$). Trends for the DW curve were a slight increase for the lower K levels, followed by a flattening of the curve. No zones were therefore demarcated.

CC effects. The range of CC mean values was 14.06 to 15.23. A negative r value of -0.055 indicated a negative relationship which was not significant at the 5% level. As illustrated in the essentially flat response curve presented in Figure 21, there were no perceptible zones.

%K effects. Mean values of %K ranged from 1.09 to 2.76. Treatment means showed generally increasing %K values with increments of K. Overall data for %K and K levels were correlated and found to be significantly related ($r = 0.918$, $p < .01$). The response curve of %K plotted against K levels is presented in Figure 22. The zone of deficiency, marked by sharply increasing %K values over a domain of 12.5 ppm, was discerned, followed by a zone of transition, marked by less rapidly increasing %K values over a domain of 62.5 ppm, and a zone of adequacy, marked by increasingly constant %K values over approximately 75 ppm. Differences were found to be significant between all means (Anova, $p < .05$), except for those K levels 75 ppm and higher.

%N and %P effects. %N mean values showed an increasing trend up to the 25 ppm K level, followed by a decreasing one for the higher K levels. No significant differences for %P means were detected with increasing K levels.

Table 9

Effects of K Levels on Visual Ratings of Turf Pots and Dried Weights, Chlorophyll Content, and Percent Composition of N, P, and K, Respectively, of Leaf Tissue of Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

K Levels	VR	DW	CC	%N	%P	%K
0	2.04 a	0.63 a	14.06 a	4.45 ab	0.64	1.09 a
6.25	2.75 b	0.91 b	14.47 a	4.53 bc	0.72	1.36 b
12.50	3.38 c	1.19 de	15.23 c	4.53 bc	0.55	1.62 c
25.00	3.50 cd	1.08 cd	15.22 c	4.92 e	0.56	2.14 d
50.00	3.96 f	1.23 e	15.17 bc	4.66 cd	0.50	2.43 e
75.00	3.58 cd	1.13 de	14.87 abc	4.69 d	0.58	2.61 f
100.00	3.83 ef	1.09 cd	14.82 abc	4.60 cd	0.56	2.67 f
125.00	3.71 de	1.00 bc	14.79 abc	4.55 bcd	0.58	2.75 g
150.00	3.67 de	1.12 cde	14.46 a	4.38 a	0.65	2.76 g
BLSD	0.23	0.13	0.64	0.15	----	0.07

For each column, means for treatments followed by the same letter do not differ significantly (BLSD = 0.05).

Table 10

Regression Equations and Correlation Coefficients Between the Evaluation Parameters and K Levels on Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

Comparison	Regression Equation	r
K Level(X) _vs_ VR(Y)	Y = 2.686 + 0.277 LOG(X)	0.603**
K Level(X) _vs_ DW(Y)	Y = 1.014 + 0.021 LOG(X)	0.649**
K Level(X) _vs_ CC(Y)	Y = 15.054 - 0.046 LOG(X)	-0.251**
K Level(X) _vs_ %K(Y)	Y = 0.537 + 0.464 LOG(X)	0.918**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

Table 11

Regression Equations and Correlation Coefficients for Parameters Used to Evaluate K Treatment Effects on Tifdwarf Bermudagrass Grown Under Glasshouse Conditions

Comparison	Regression Equation	r
1) DW(X) _vs_ VR(Y)	Y = 2.095 + 1.391(X)	0.535**
2) CC(X) _vs_ VR(Y)	Y = -0.341 + 0.262(X)	0.313**
3) %K(X) _vs_ VR(Y)	Y = 1.790 + 0.810(X)	0.728**
4) %K(X) _vs_ DW(Y)	Y = 0.650 + 0.180(X)	0.422**
5) %K(X) _vs_ CC(Y)	Y = 14.020 + 0.350(X)	0.298**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

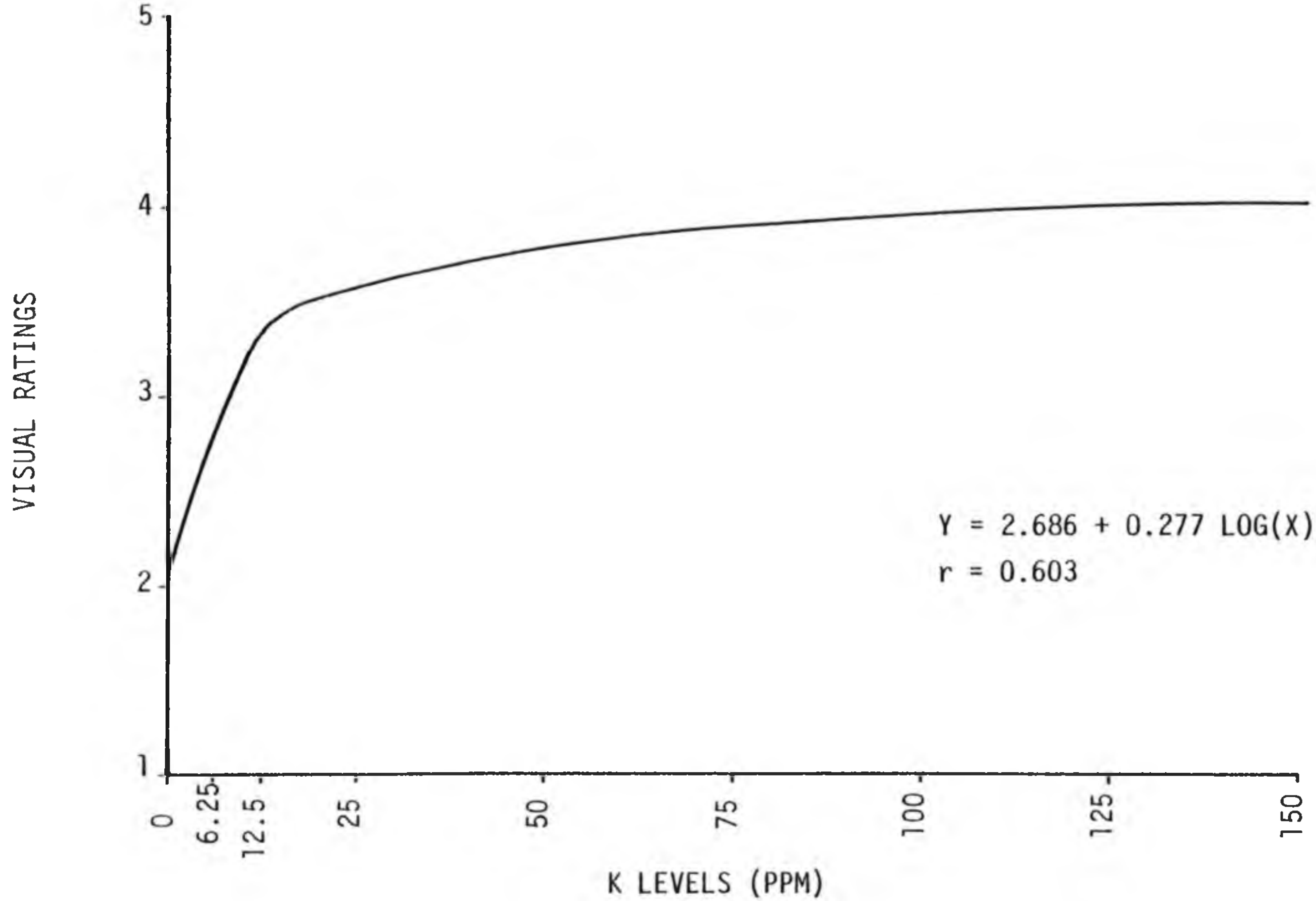

Figure 19. The effect of K levels on visual ratings.

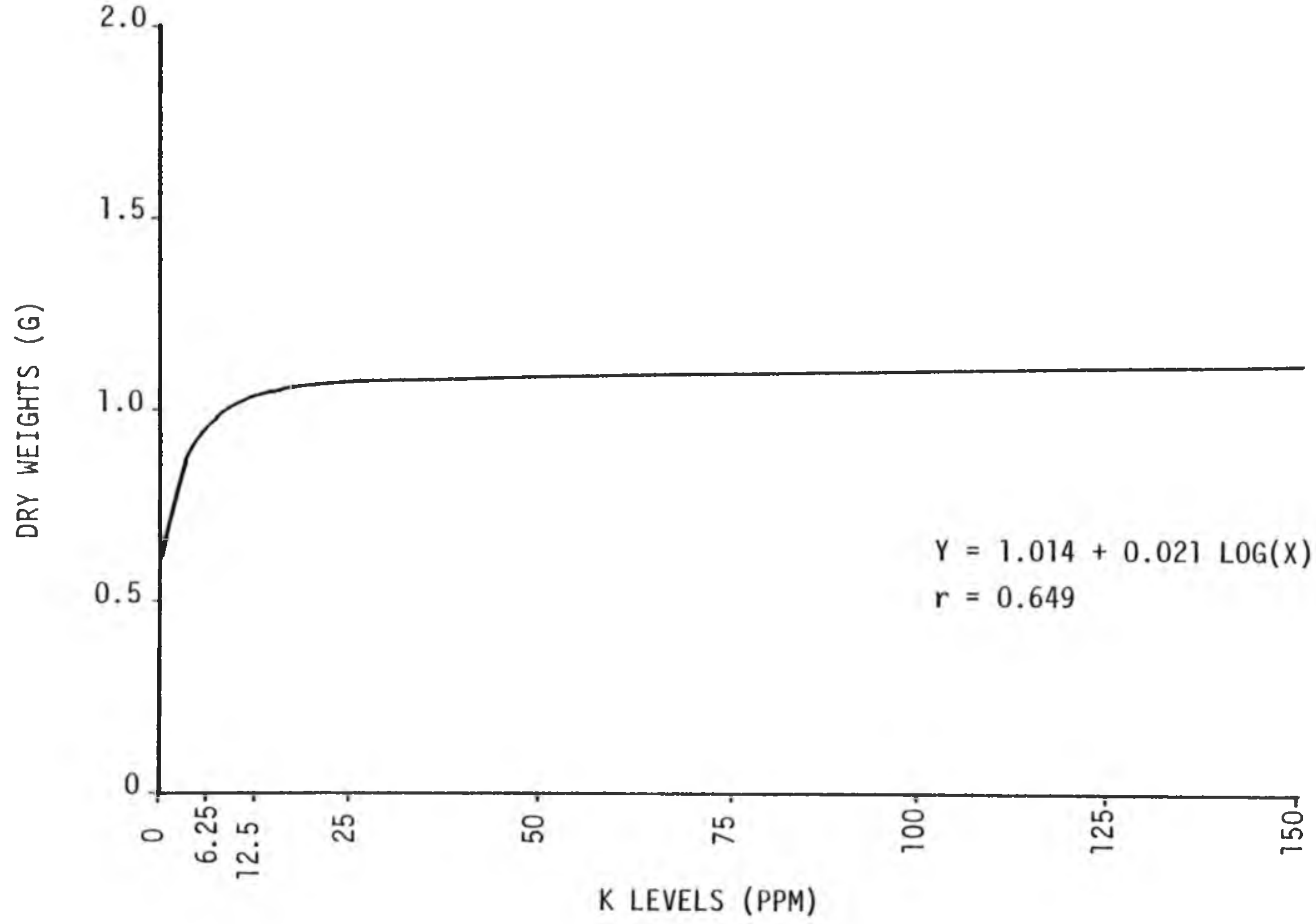

Figure 20. The effect of K levels on dry weight yields.

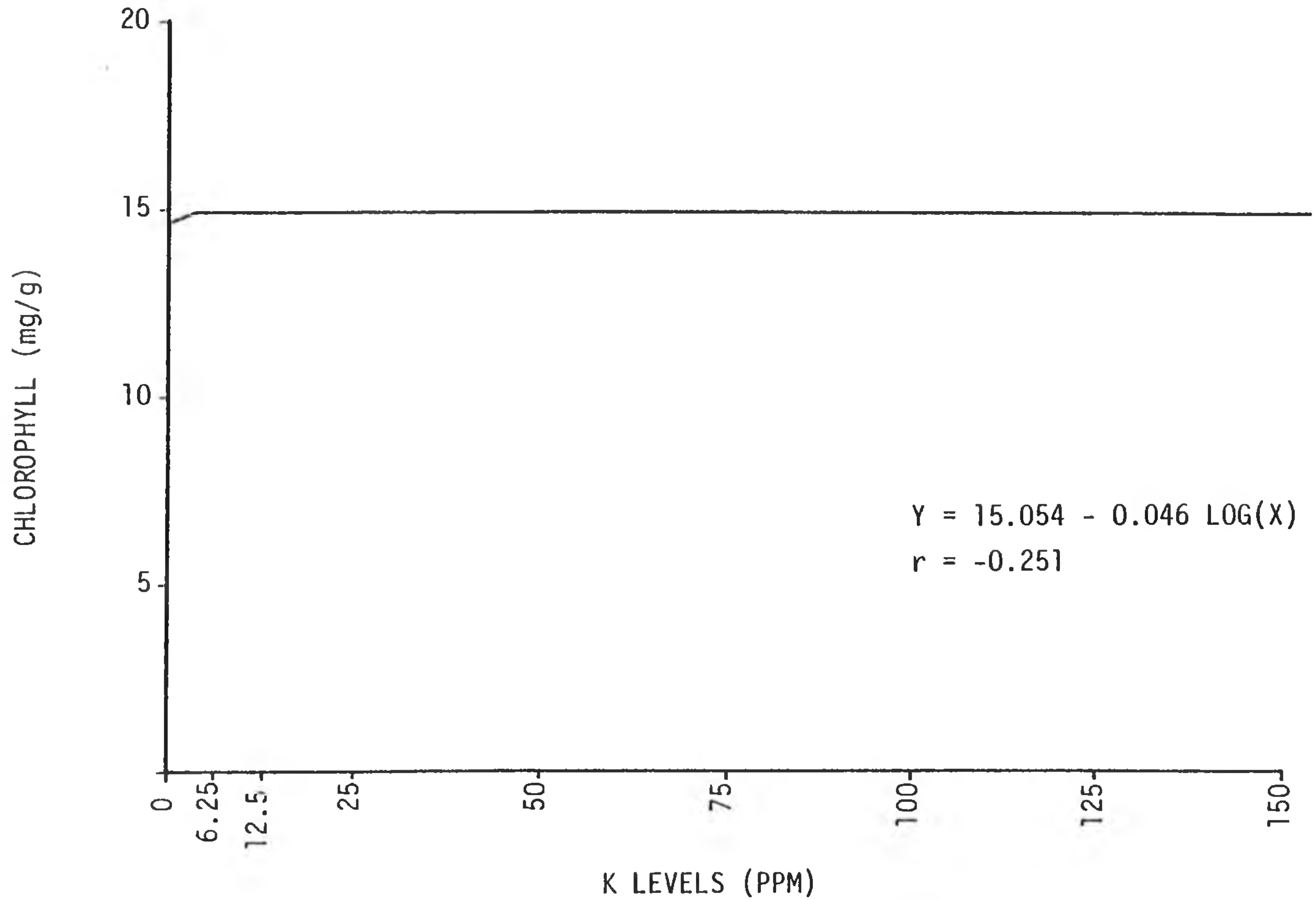

Figure 21. The effect of K levels on chlorophyll content.

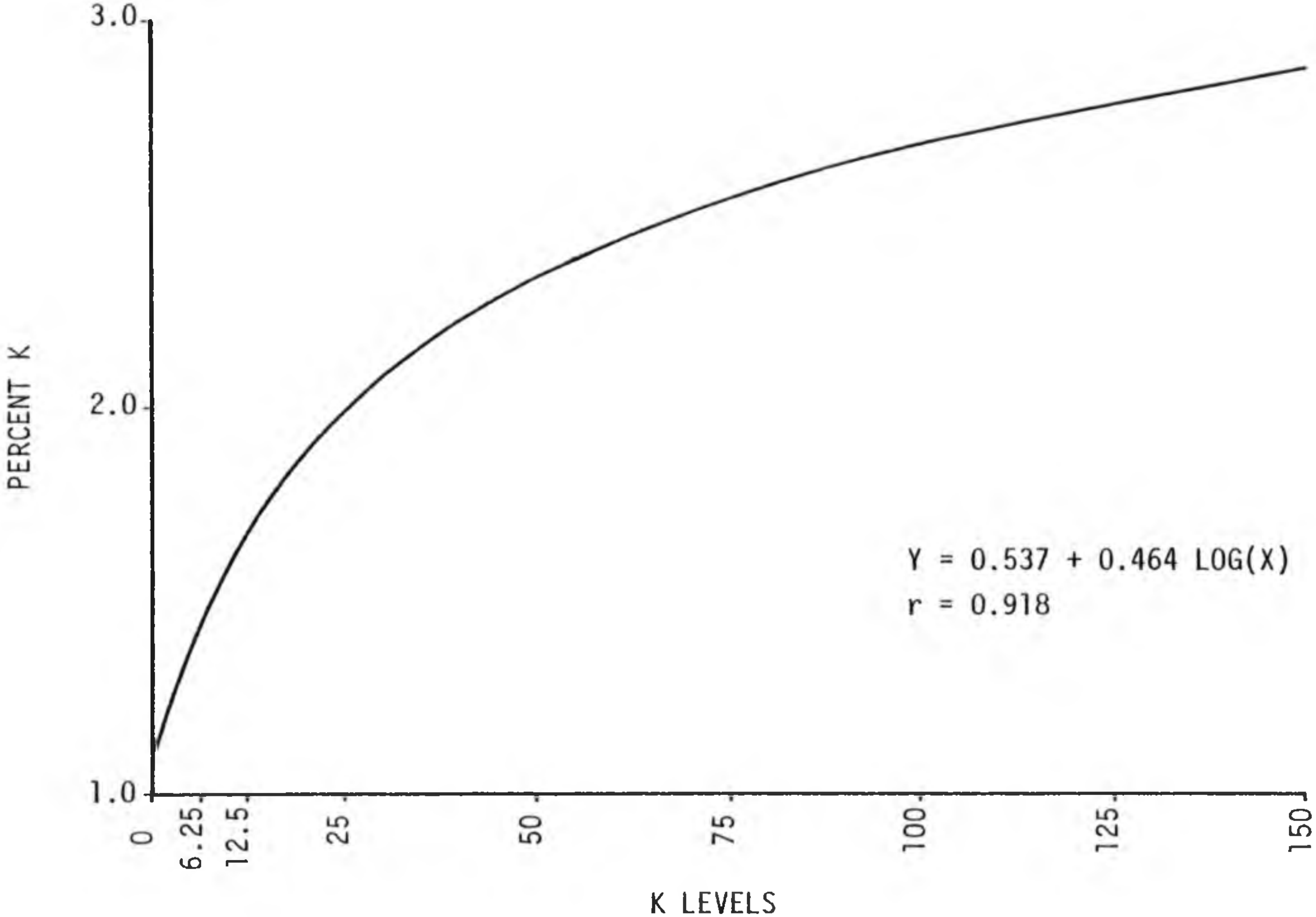

Figure 22. The effect of K levels on percent K in the tissue.

Comparison of Parameters by Correlation and Regression

The primary parameters, VR, DW, CC, and %K, used in evaluating K treatment effects were found to be significantly correlated one with another at the 1% level. Correlation coefficients and regression equations for the five comparisons are presented in Table 11. Graphical relationships were found to be consistently linear with positive slopes (Figures 23 through 27).

A highly correlated relationship resulted between DW and VR ($r = 0.535$, $\underline{p} < .01$). Interpolation of the resultant regression line, shown in Figure 23, indicated that approximately 0.65 g of DW was associated with an "acceptable" VR of 3. Increasing DW values in excess of 0.65 g reflected turf quality approaching luxuriance, while decreasing DW values less than 0.65 g reflected turf of poor visual quality.

The comparison of CC with VR resulted in a highly correlated relationship, although lower than that obtained for DW ($r = 0.313$, $\underline{p} < .01$). Figure 24 shows that the interpolation of the CC associated with a VR of 3 was about 13 mg/g.

The highest correlation obtained for all comparisons made was for %K with VR ($r = 0.728$, $\underline{p} < .01$). Interpolation of the regression line shown in Figure 25 indicated that K content of 1.5% was associated with a VR of 3.

The correlations of %K with DW and CC were significant ($r = 0.422$ and $r = 0.298$, respectively); their graphs are shown in Figures 26 and 27, respectively.

Relative to the other comparisons made, the correlations between CC and VR, as well as between %K and CC, were the lowest.

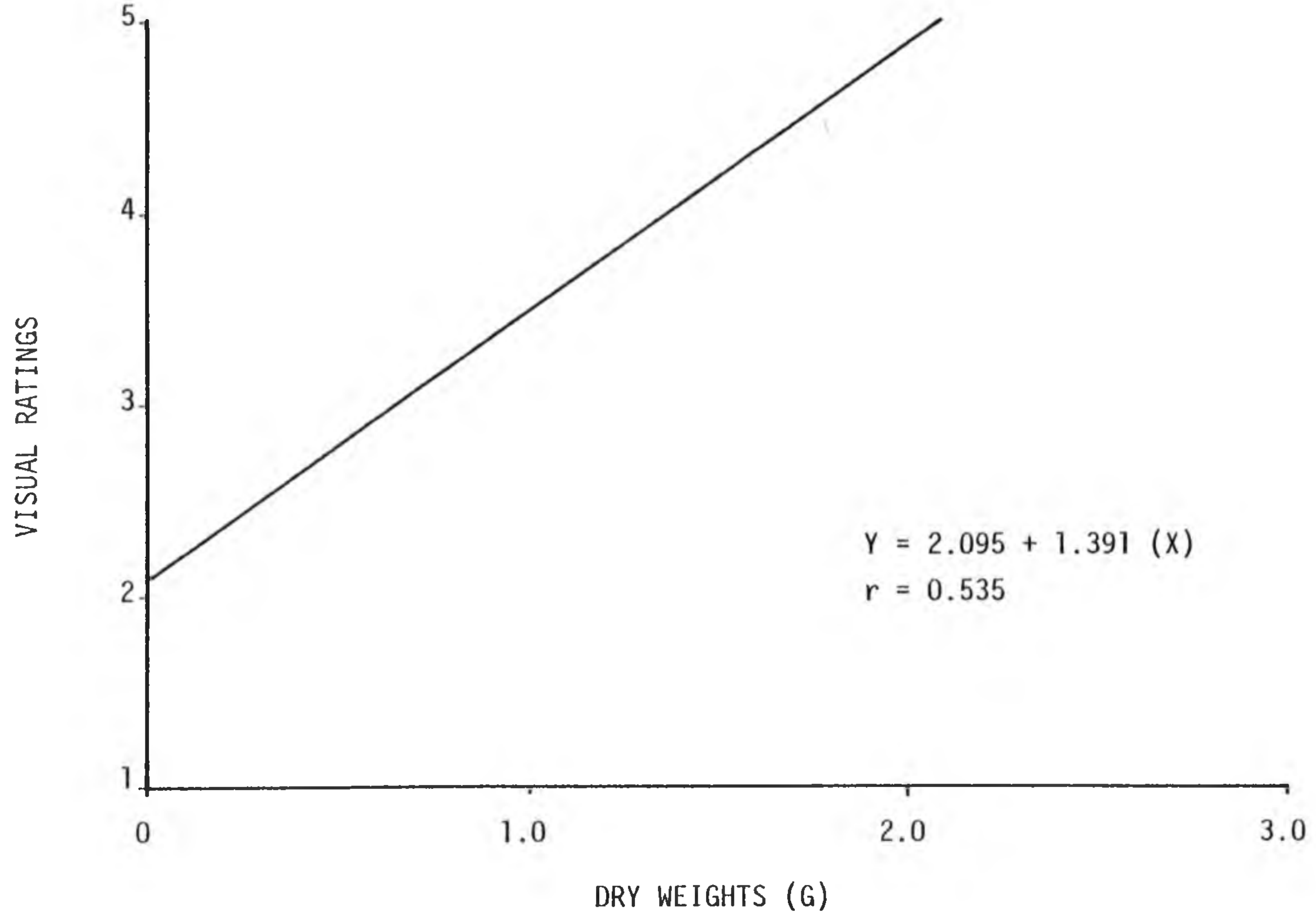

Figure 23. The relationship between visual ratings and dry weight.

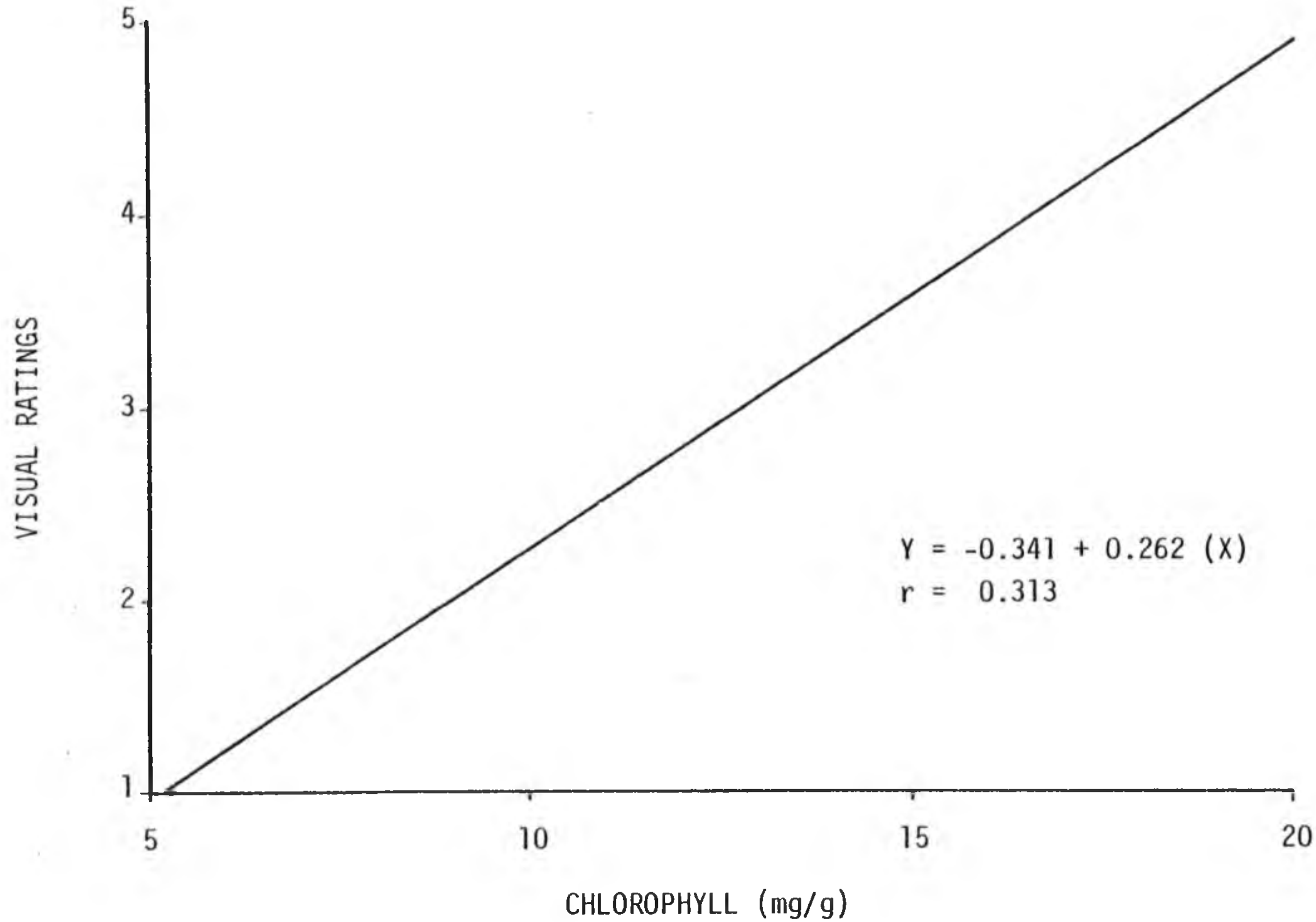

Figure 24. The relationship between visual ratings and chlorophyll.

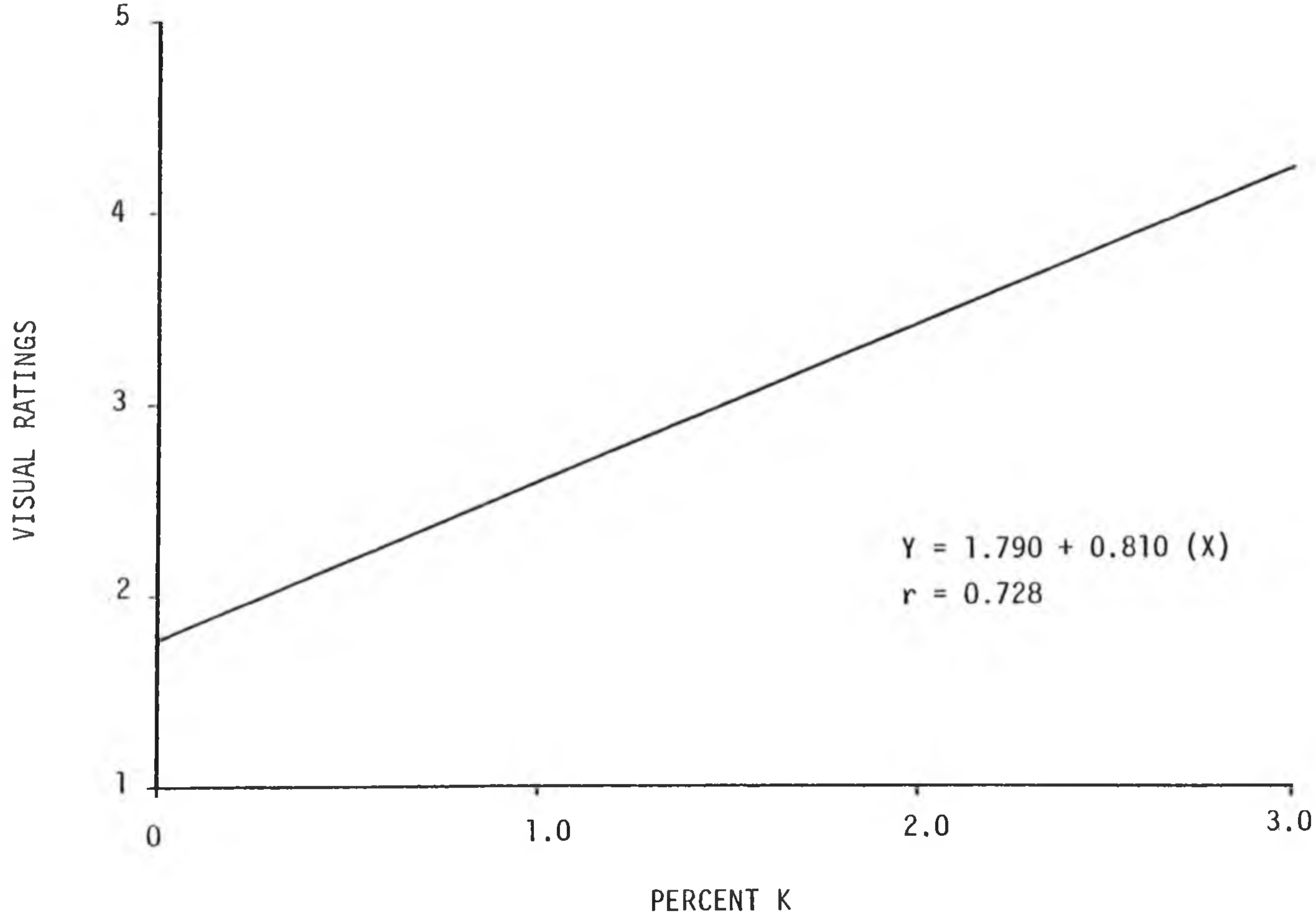

Figure 25. The effect of percent K on visual ratings.

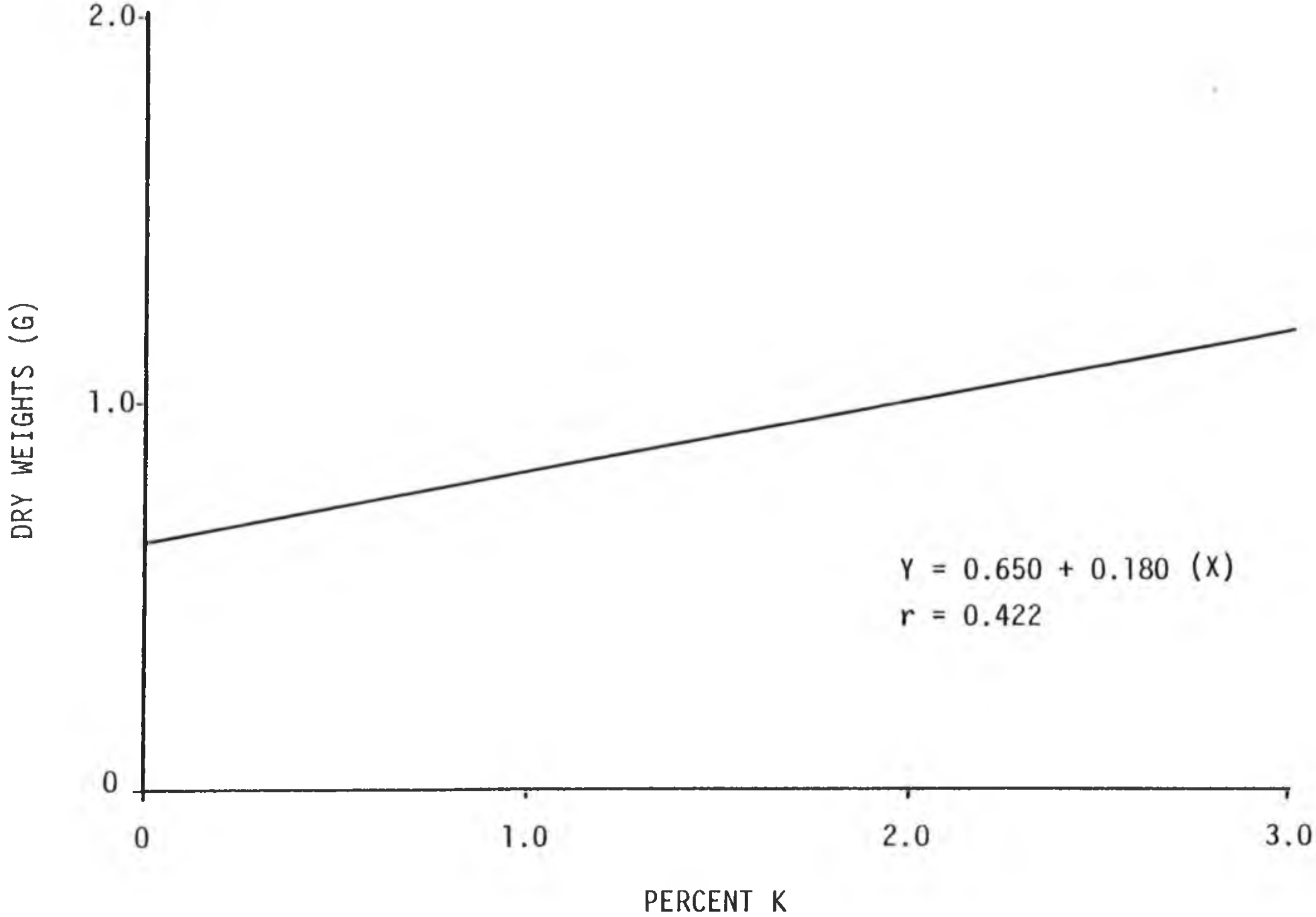

Figure 26. The effect of percent K on dry weight yields.

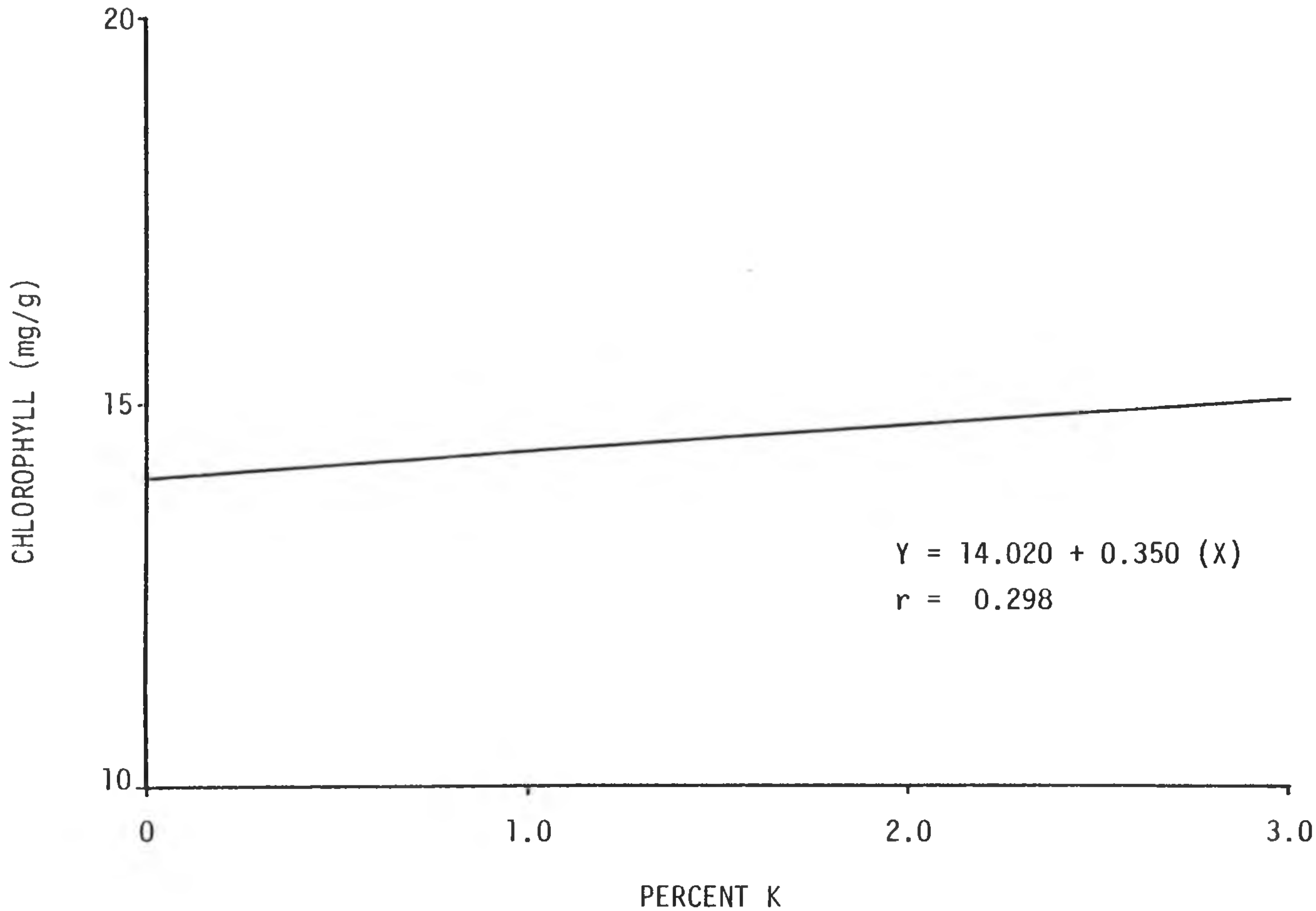

Figure 27. The effect of percent K on chlorophyll content.

Experiment II: Outdoor Environment Studies

Nitrogen Treatments

The main N treatment effects are presented in Table 12 as mean values. In general, a positive relationship existed for all parameters. Although some of the differences between means were not significant, mean values tended to increase with each increment of N level. Correlation and regression analysis were performed for VR, DW, CC, and %N data and the results are presented in Table 13. Since broader differences were consistently observed for lower N levels, resultant curvilinear graphs of the positive functional relationships of N levels with individual parameters were negatively accelerated.

VR effects. As in Experiment I, turf pots treated with low N levels (< 25 ppm) were first to show evidence of N deficiency. VR means ranged from 1.04 to 2.13. High N levels (> 100 ppm) resulted in VR ranging from 3.75 to 4.29. Intermediate N levels of 50 and 75 ppm N produced turf of "acceptable" (VR = 3) visual quality; VR were 2.92 and 3.46, respectively. Overall, VR and N levels were highly correlated ($r = 0.966$, $p < .01$). The curve illustrating this correlation is shown in Figure 28. Three zones were evident as in Experiment I. The zone of deficiency corresponded to that area in the graph between 6.25 and 25 ppm, where mean differences were found to be significant (Anova, $p < .05$); the zone of transition between 25 and 100, where mean differences, although significant, were not as broad as those for the first three N levels; and, the zone of adequacy 100 ppm N and higher, where the associated mean differences were not found to be significant.

DW effects. Turf pots treated with higher levels of N tended to produce greater amounts of DW at a significant level ($r = 0.907$, $p < .01$). Due to broader differences in means for lower N levels, the resultant curve was negatively accelerated (Figure 29). Although high and low yield separation could be made, the zone of adequacy was not easily demarcated due to the gradual deceleration in slope.

CC effects. The correlation between CC and N levels was found to be significant ($r = 0.952$, $p < .01$). Curve trends evident in Figure 30 were similar to those for VR. "Leveling off" begins at 100 ppm N, with the exception of the mean CC value at 175 ppm which was significantly greater than those preceding it. Significant differences were obtained between mean values for N levels between 6.25 and 100 ppm.

%N effects. Results similar to those previously reported for VR, CC, and DW were obtained for the effects of increasing N levels on %N. Data trends were, in fact, essentially identical to those obtained for VR. As seen in Figure 31, an increasing trend was evident up to the 100 ppm N level with "leveling off" occurring at 125 ppm and higher.

%P and %K effects. Supplementary Anova were performed on %P and %K data, resulting in significant differences between means for both %P and %K. Positive trends in parameter values with increasing N levels were evident for both. The %K mean values were found to vary in similar fashion to that of VR means.

Table 12

Effects of N Levels on Visual Ratings of Turf Pots and Dried Weights, Chlorophyll Content, and Percent Composition of N, P, and K, Respectively, of Leaf Tissue of Tifdwarf Bermudagrass Grown Under Field Conditions

N Levels	VR	DW	CC	%N	%P	%K
6.25	1.04 a	0.13 a	5.41 a	2.49 a	0.37 a	1.43 a
12.50	1.46 b	0.19 a	5.98 b	3.01 b	0.39 ab	1.59 b
25.00	2.13 c	0.26 b	8.26 c	3.37 c	0.45 abc	1.69 c
50.00	2.92 d	0.60 c	11.31 d	3.85 d	0.46 bc	1.96 d
75.00	3.46 e	0.77 d	12.25 e	4.17 de	0.46 bc	2.19 e
100.00	3.75 f	1.01 e	13.07 f	4.52 e	0.42 abc	2.32 f
125.00	4.13 g	1.42 f	13.46 f	5.01 f	0.47 bcd	2.48 g
150.00	4.21 g	1.60 g	13.54 fg	5.01 f	0.49 cd	2.50 g
175.00	4.29 g	1.82 h	14.07 g	5.26 f	0.55 d	2.56 g
BLSD	0.19	0.07	0.55	0.36	0.09	0.12

For each column, means for treatments followed by the same letter do not differ significantly (BLSD = 0.05).

Table 13

Regression Equations and Correlation Coefficients Between the Evaluation Parameters and N Levels on Tifdwarf Bermudagrass Grown Under Field Conditions

Comparison	Regression Equation	r
N Level(X) vs VR(Y)	Y = -1.089 + 1.05 LOG(X)	0.966**
N Level(X) vs DW(Y)	Y = -1.090 + 0.496 LOG(X)	0.907**
N Level(X) vs CC(Y)	Y = -0.423 + 2.855 LOG(X)	0.952**
N Level(X) vs %N(Y)	Y = 0.865 + 0.815 LOG(X)	0.858**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

Table 14

Regression Equations and Correlation Coefficients for Parameters Used to Evaluate N Treatment Effects on Tifdwarf Bermudagrass Grown Under Field Conditions

Comparison	Regression Equation	r
1) DW(X) vs VR(Y)	Y = 1.507 + 1.778 (X)	0.895**
2) CC(X) vs VR(Y)	Y = -0.560 + 0.333 (X)	0.919**
3) %N(X) vs VR(Y)	Y = -0.98 + 0.99 (X)	0.864**
4) %N(X) vs DW(Y)	Y = -1.08 + 0.48 (X)	0.831**
5) %N(X) vs CC(Y)	Y = -0.094 + 2.68 (X)	0.848**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

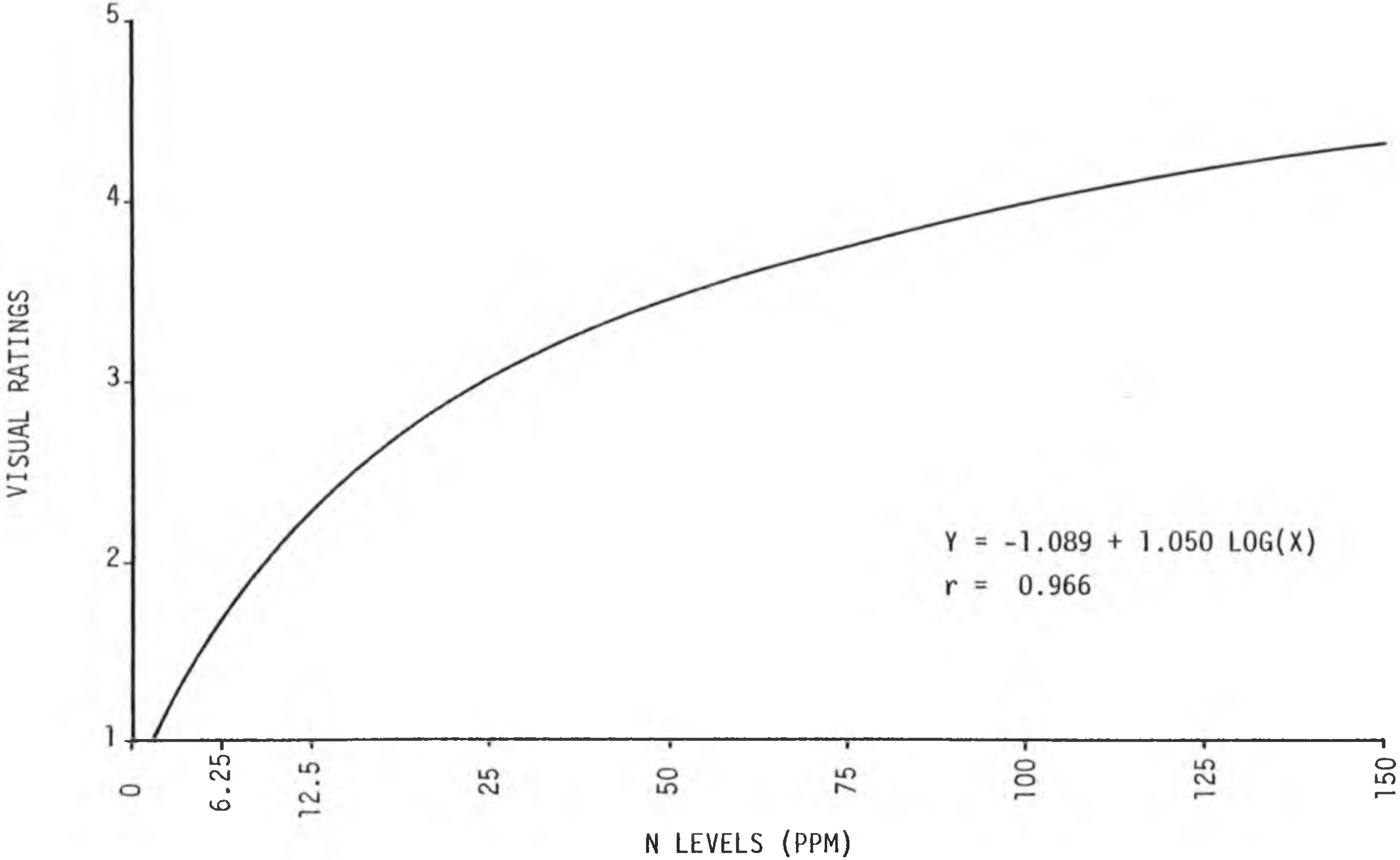

Figure 28. The effect of N levels on visual ratings.

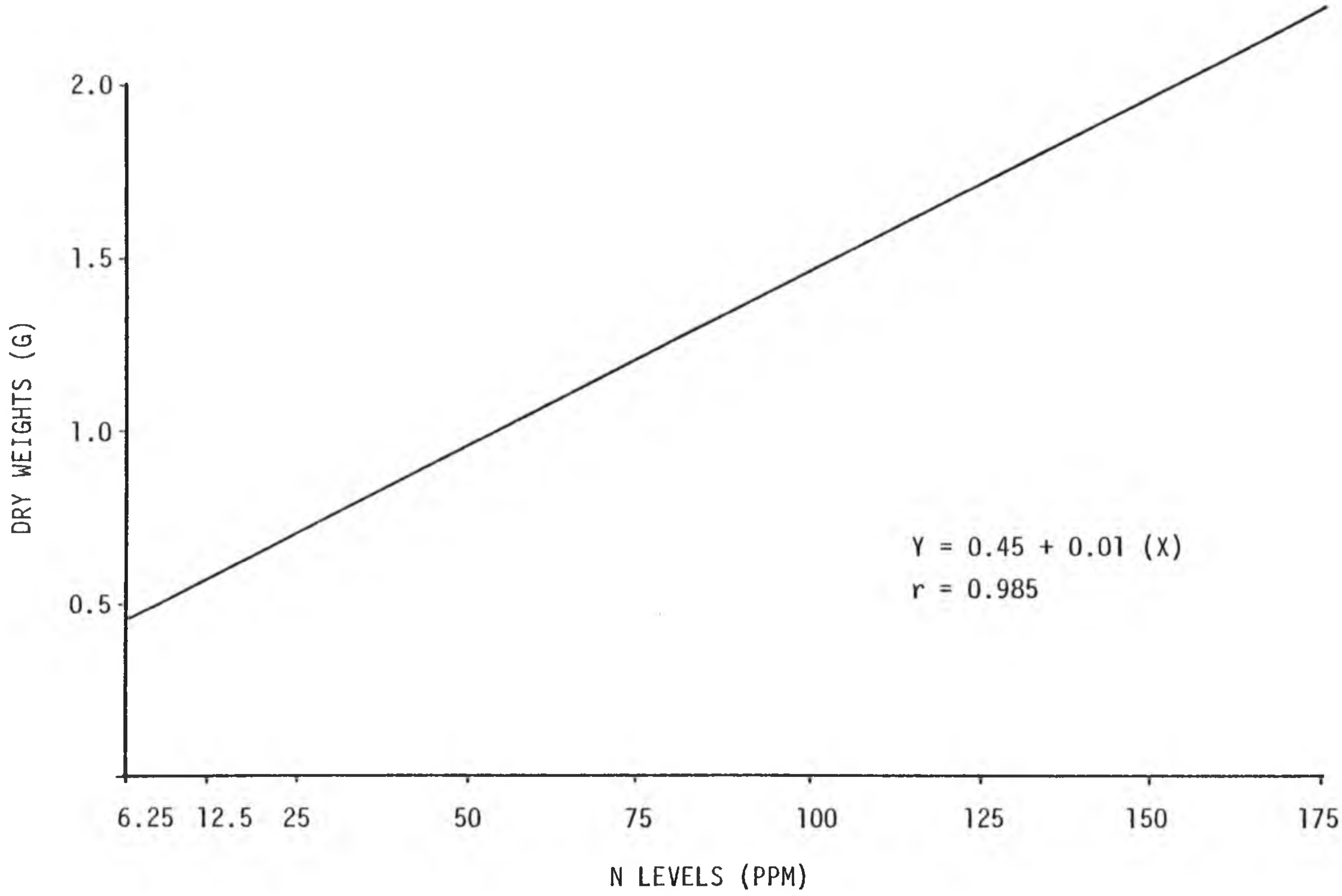

Figure 29. The effect of N levels on dry weight yields.

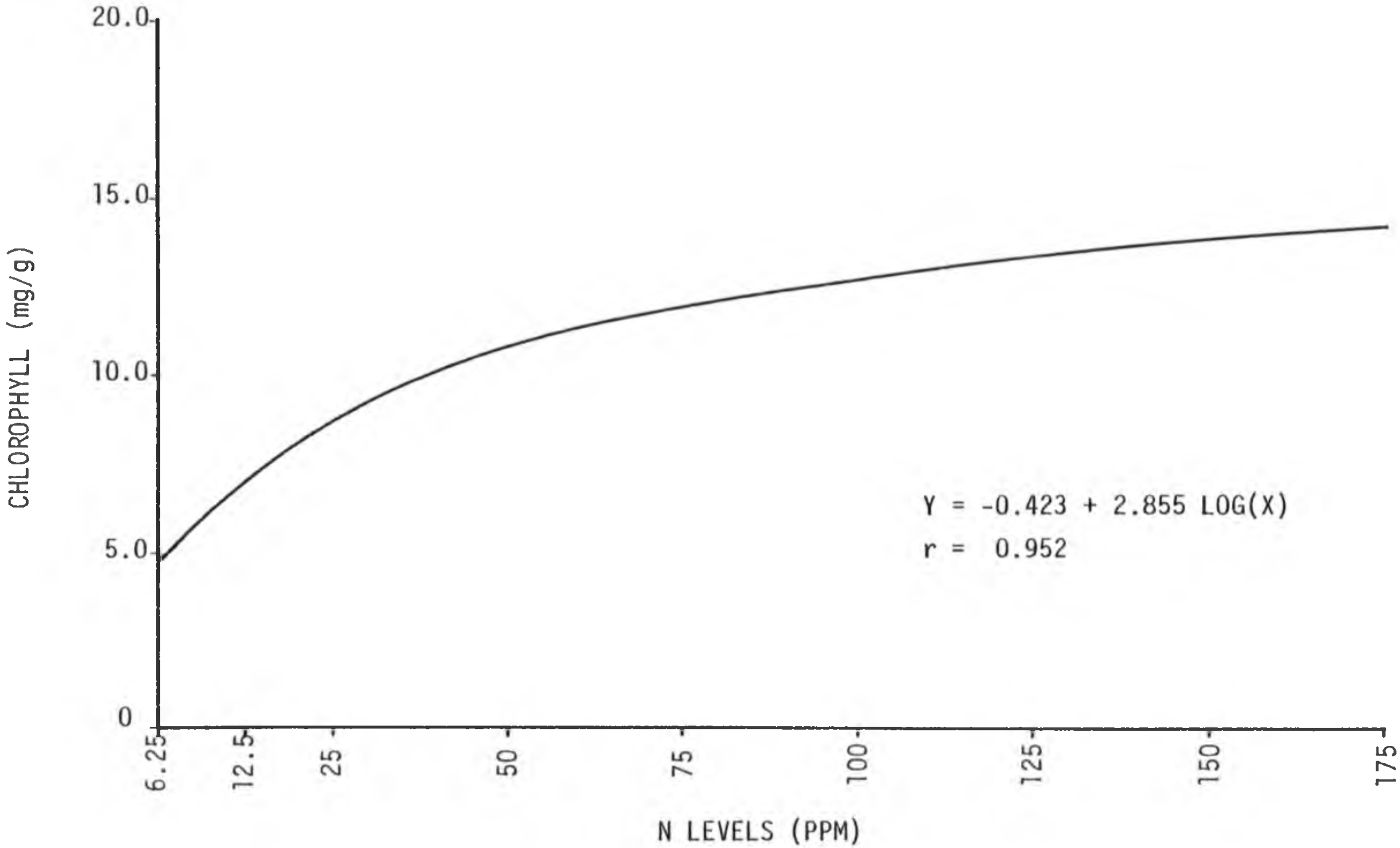

Figure 30. The effect of N levels on chlorophyll content.

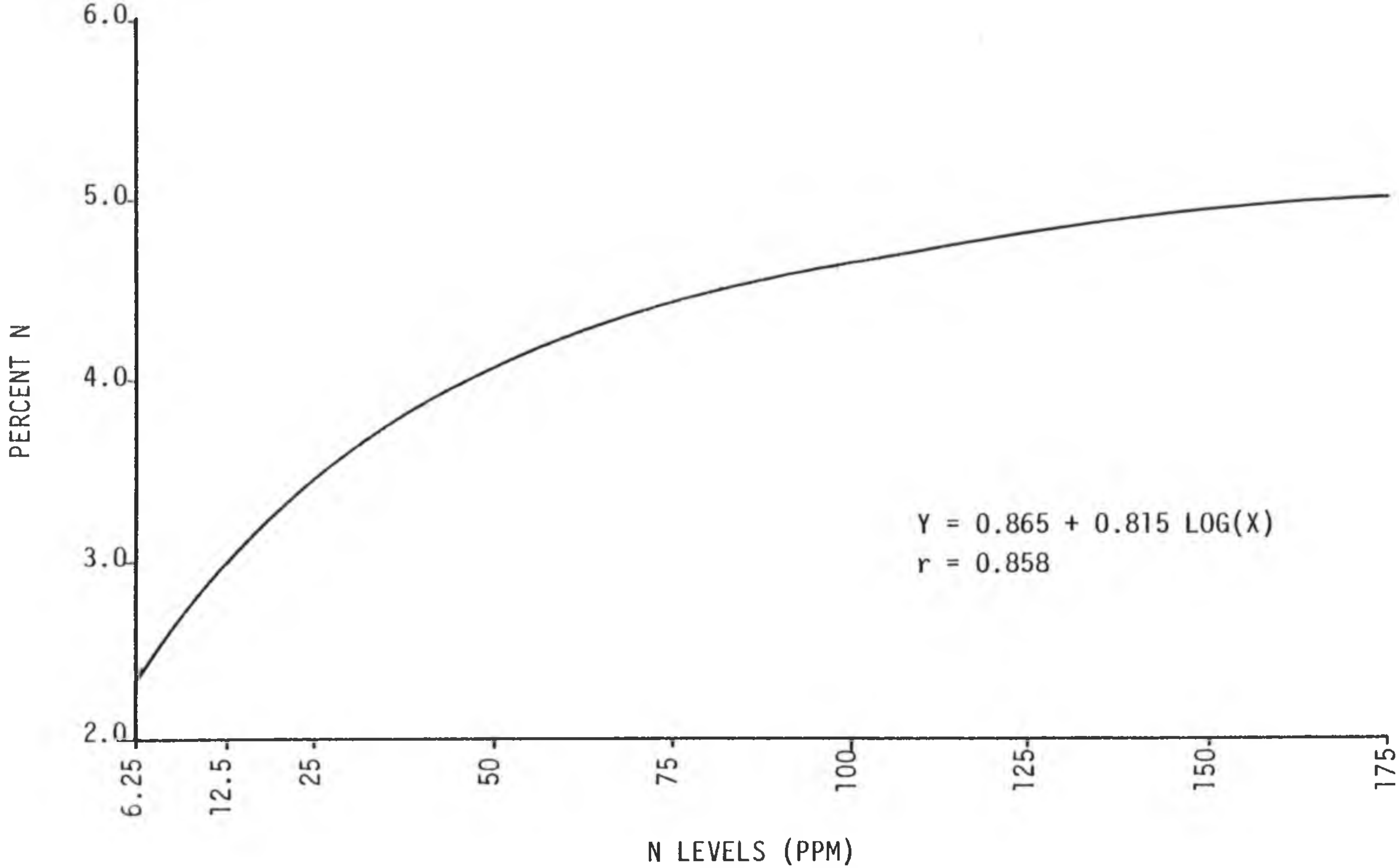

Figure 31. The effect of N levels on percent N in tissue.

Comparison of Parameters by Correlation and Regression

The primary parameters, VR, DW, CC, and %N, used in evaluating N treatments were found to be significantly correlated, one with another at the 1% level. Correlation coefficients and regression equations for the five comparisons are presented in Table 14. Graphical representations of the relationships were consistently linear with positive slopes; trends observed in one graph, therefore may be generalized to another, given significantly high correlations (Figures 32 through 36).

Relative to other parameter comparisons involving VR, the correlation between DW and VR was highly significant ($r = 0.895$). Interpolation of the resultant regression line in Figure 32 indicated that a DW of 0.85 g was associated with an "acceptable" VR of 3. Increasing DW values in excess of this value might be said to approach luxuriance; less than that, poor visual quality.

The relationship between CC and VR resulted in the highest correlation value ($r = 0.919$) for all the comparisons. Figure 33 shows that an acceptable VR was associated with a CC of about 10.6 mg/g.

Percent N compared with VR yielded an r value of 0.864 and a 4.0% N value associated with a VR of 3 (Figure 34).

The correlations of %N with VR, DW, and CC were consistently high ($r = 0.864$, $r = 0.831$, and $r = 0.848$, respectively). Compared to the other comparisons made, %N and DW correlated the least.

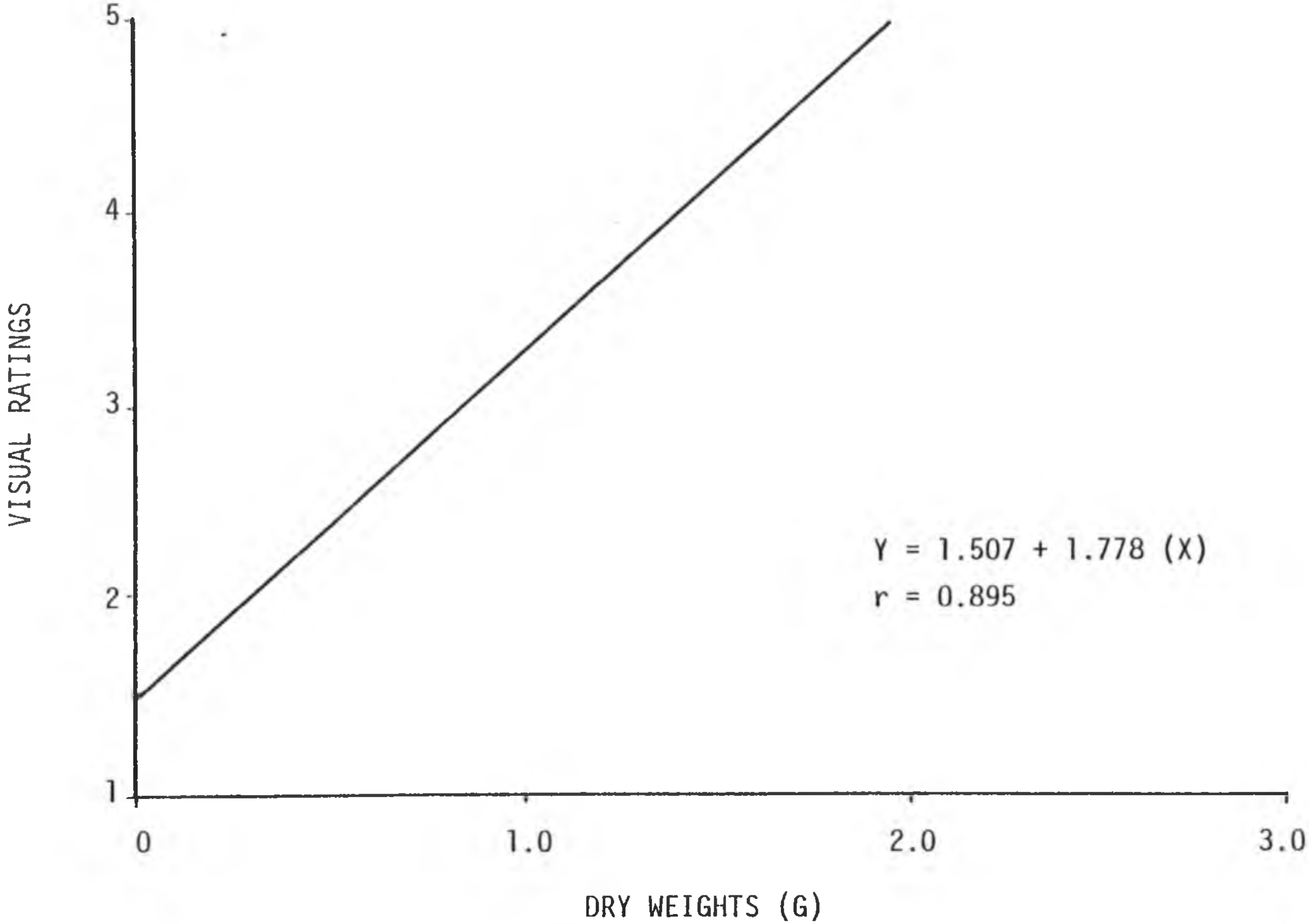

Figure 32. The relationship between visual ratings and dry weight yields.

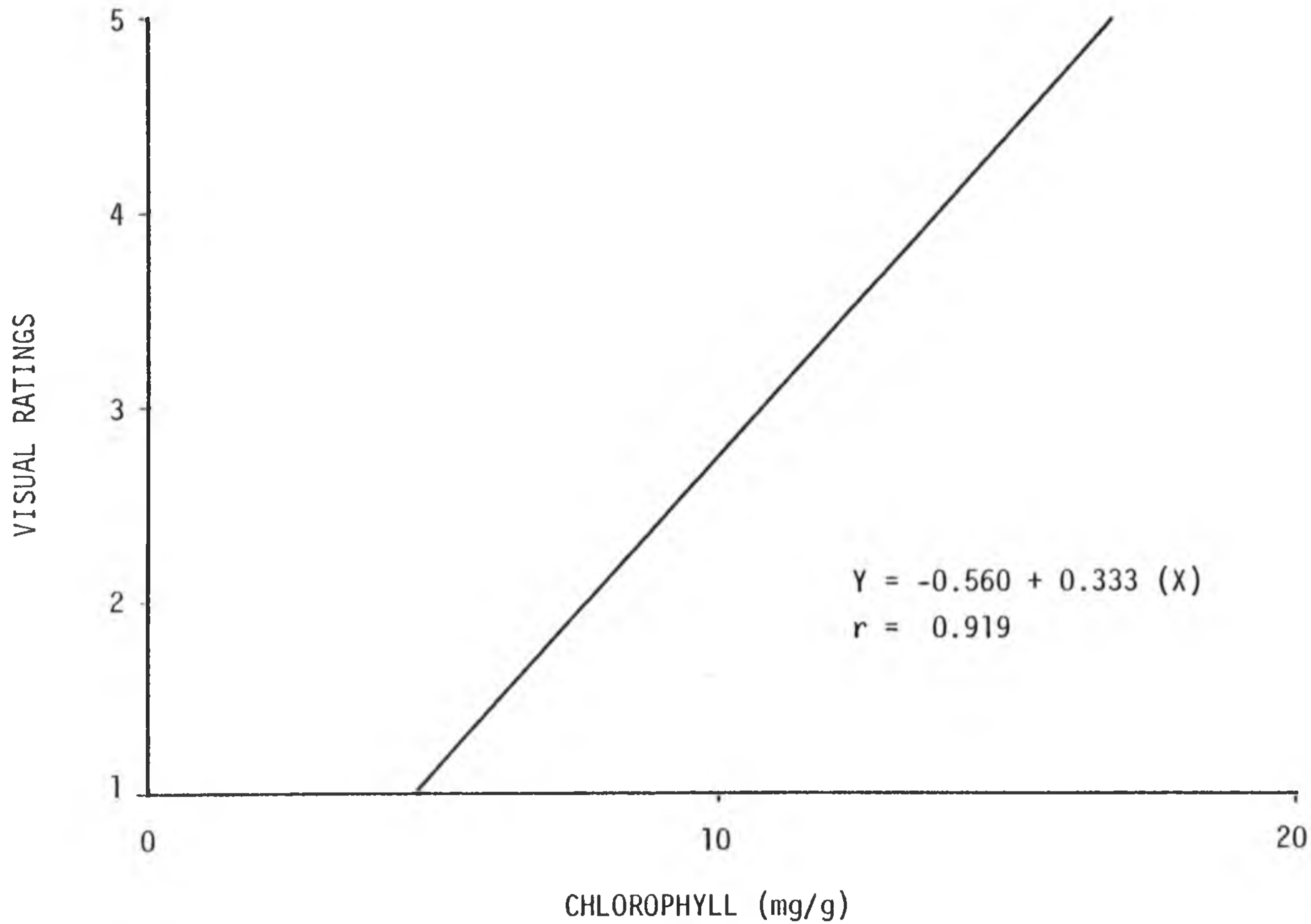

Figure 33. The relationship between visual ratings and chlorophyll content.

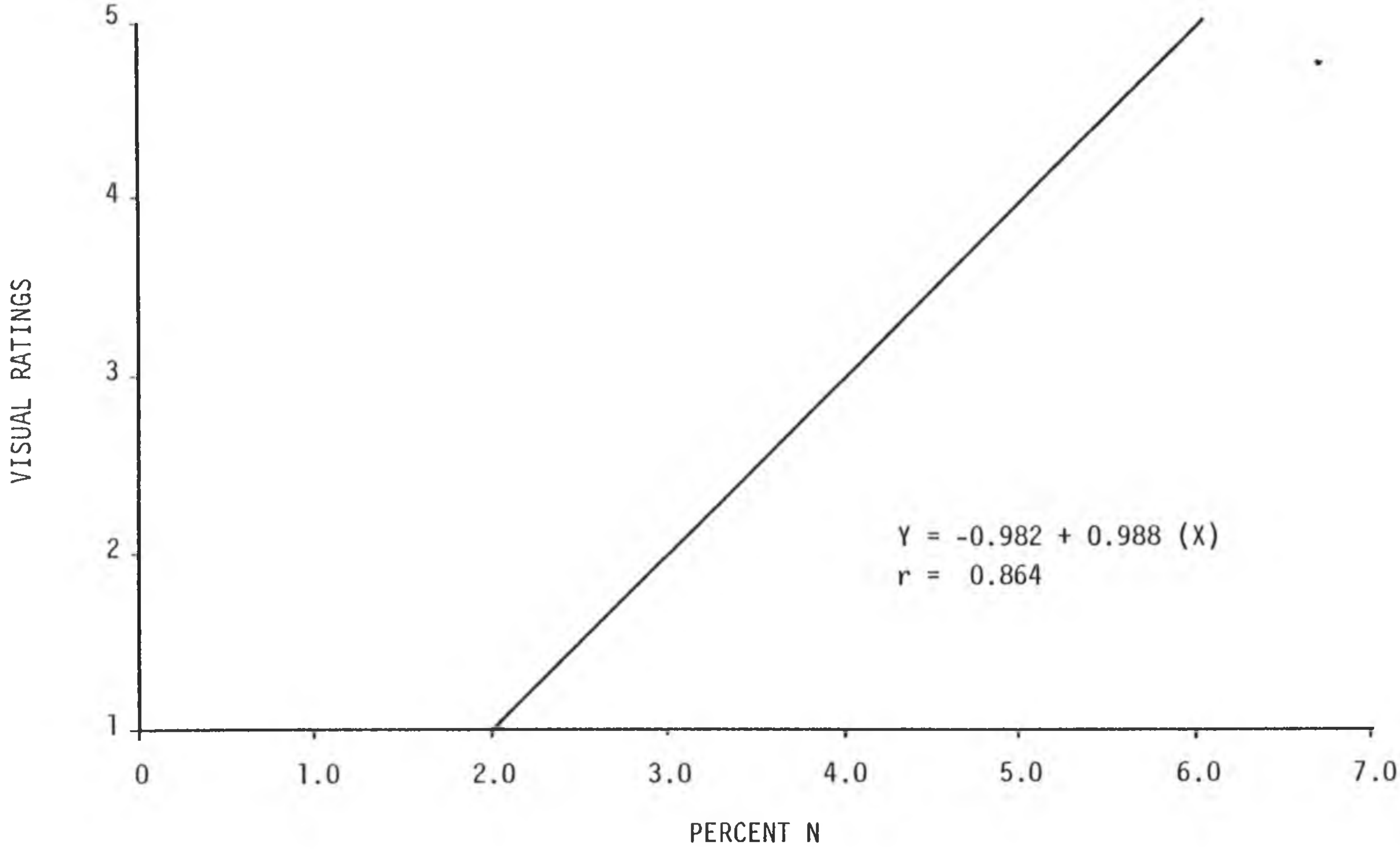

Figure 34. The effect of percent N on visual ratings.

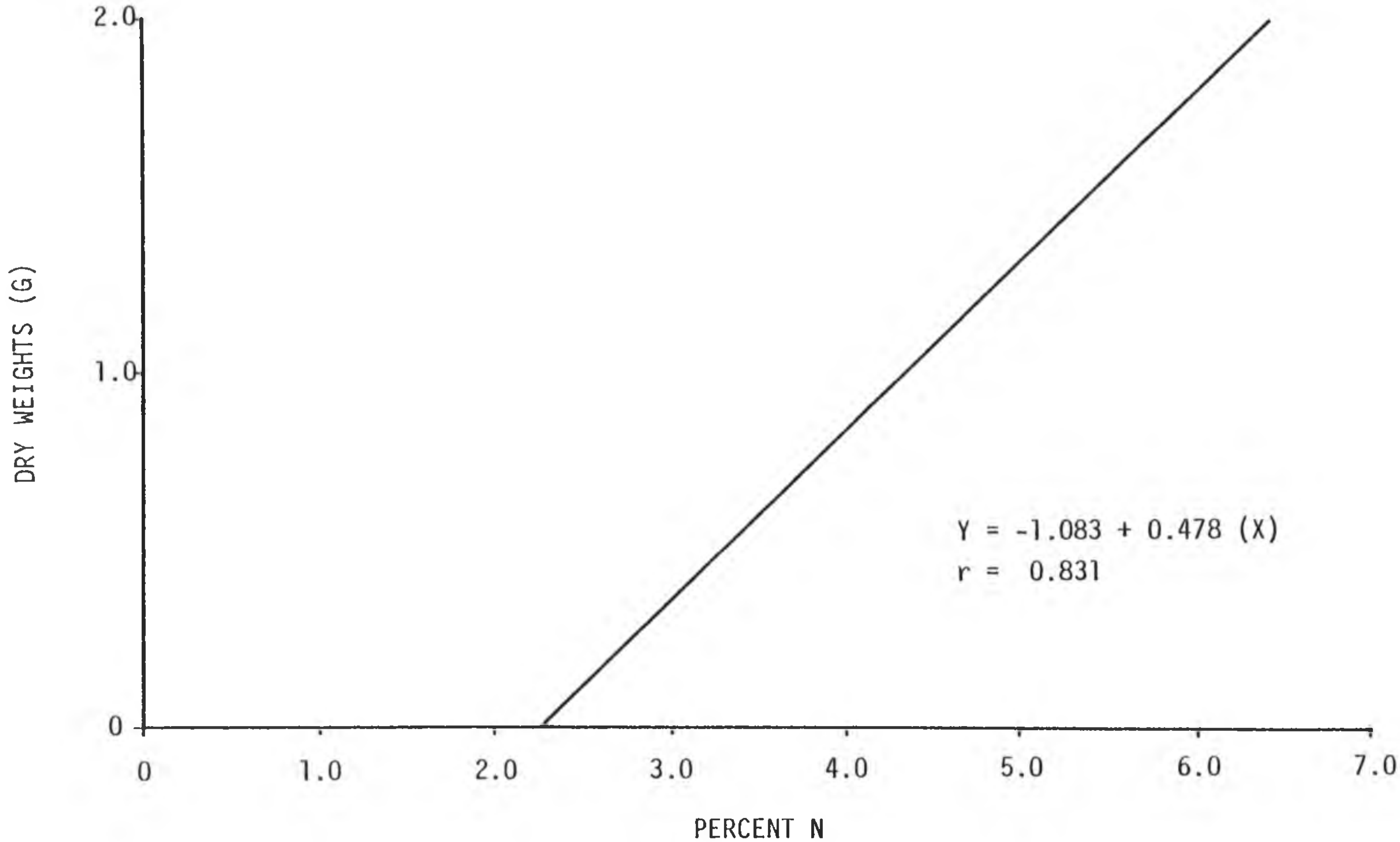

Figure 35. The effect of percent N on dry weight yields.

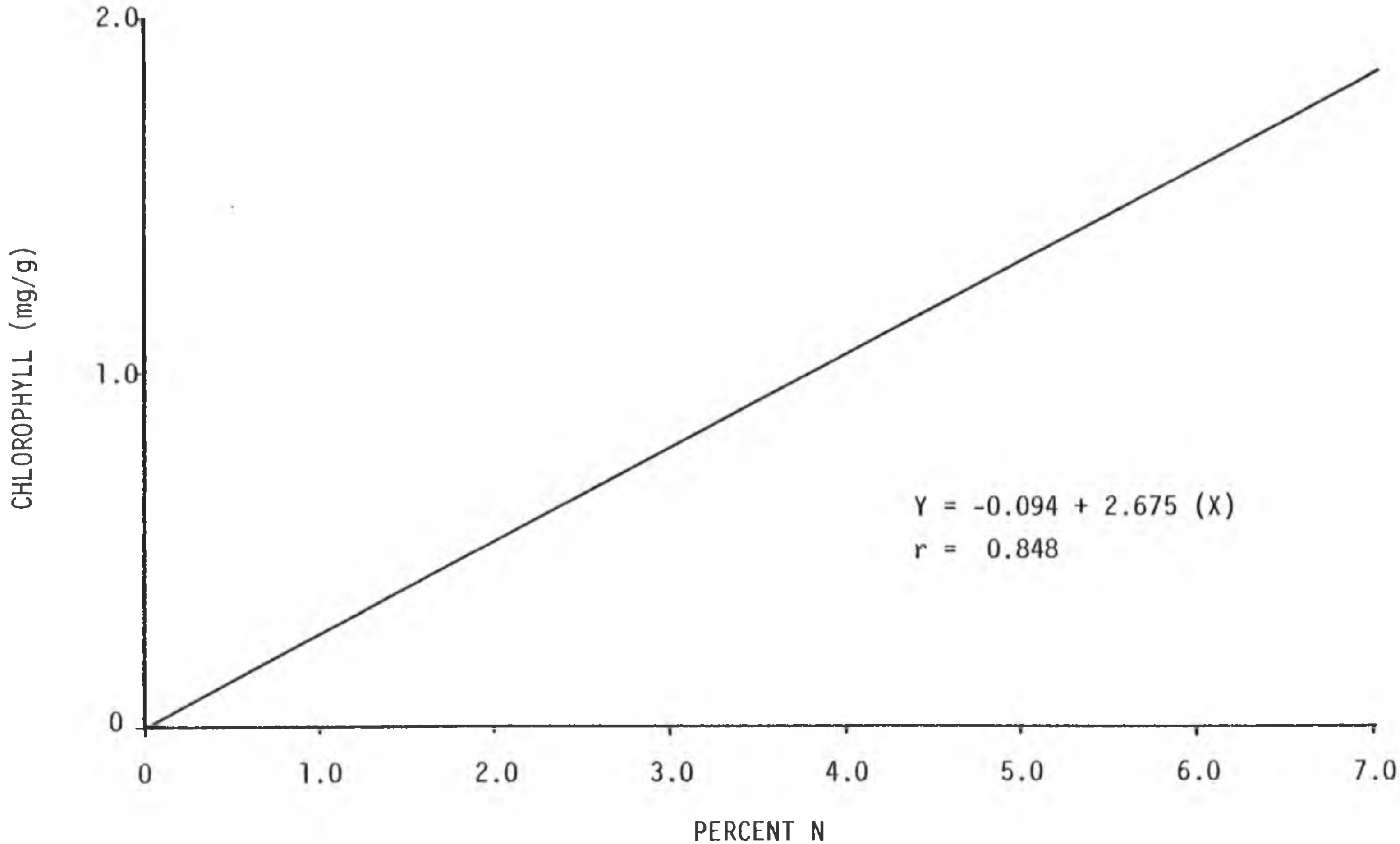

Figure 36. The effect of percent N on chlorophyll content.

Phosphorus Treatments

The effects of increasing P levels on VR, DW, CC, and percent composition of N, P, and K are presented as mean values in Table 15. Although some of the differences between mean values of these parameters were not significant, distinctly positive trends were apparent for VR, DW, CC, and %P. Broader differences were observed for lower P levels, while for higher P levels, treatment differences were smaller or even non-existent. Correlation and regression analysis were performed on VR, DW, CC, and %P data; results are tabulated in Table 16. Resultant curvilinear graphs of the positive relationships of P levels with parameter values were negatively accelerated.

VR effects. The means of VR data ranged from 1.75 to 4.83. A range of visual quality was produced, particularly at lower P levels. At the lowest level, profound deficiency symptoms were manifested; pale green color and slow, reduced growth were the primary symptoms. Similar symptoms, though not as pronounced, were observed at 4 ppm P. Increased differences in VR with increasing P fertilization occurred for the entire range of P levels. The VR mean differences between 12 and 16, and between 24 and 28 ppm P were not significant. For the overall analysis of VR, its correlation with P level was found to be highly significant ($r = 0.936$, $p < .01$). The curve of VR plotted against P levels is presented in Figure 37. Zones of deficiency, transition, and adequacy were evident; the domains were 4 ppm, 8 ppm, and 16 ppm, respectively. The area between 0 and 4 ppm corresponds to the zone of deficiency; 4 and 16 ppm to the zone of transition; and, 16 and 32 ppm to the zone of adequacy.

DW effects. DW mean values ranged from 0.66 to 1.50 g. Although a positive trend was evidenced, increase in DW values with increments of P level was not consistent beyond 12 ppm P. Of all the primary parameters, the overall correlation coefficient was lowest for DW ($r = 0.265$), albeit significant at the 1% level. From the curve illustrated (Figure 38), a zone of deficiency is easily demarcated between 0 and 4 ppm; of transition, between 4 and 12 ppm; and, of adequacy, beyond 12 ppm.

CC effects. The range of CC mean values was 9.87 to 13.81 mg/g. Similar to that indicated by DW data, a positive trend of increasing CC mean values with P levels was evident up to the 12 ppm level; "leveling off" occurred beyond this level. There was, however, some fluctuation in CC mean values for higher P levels. Nonetheless, the relationship was highly correlated ($r = 0.594$). The zone of deficiency was demarcated as falling between 0 and 4 ppm; of transition, between 4 and 8 ppm; and, of adequacy, beyond 8 ppm (Figure 39).

%P effects. Mean values of %P ranged from 0.19 to 0.45. Except for 20 and 32 ppm, increased P levels resulted in higher %P. More significant differences between means were obtained at the lower P levels than at those higher. The correlation of %P with P levels was significant ($r = 0.544$, $p < .01$). Curve trends were similar to those discussed for VR (Figure 40); in contrast, however, the zones of deficiency, transition, and adequacy were more easily demarcated. The zone of deficiency was that area between 0 and 4 ppm; of transition, between 4 and 12 ppm; and, of adequacy, 12 and beyond.

%N and %K effects. Supplementary Anova were performed on mean values of %N and %K; significant differences between means were obtained for both parameters. Means for %N at the lowest P levels increased significantly, while "leveling off" occurred at the 16 ppm P level. Percent K was constant across all P levels, except for the significantly lower %K value at 0 ppm P level.

Table 15

Effects of P Levels on Visual Ratings of Turf Pots and Dried Weights, Chlorophyll Content, and Percent Composition of N, P, and K, Respectively, of Leaf Tissue of Tifdwarf Bermudagrass Grown Under Field Conditions

P Levels	VR	DW	CC	%N	%P	%K
0	1.75 a	0.66 a	9.87 a	3.84 a	0.19 a	1.98 a
4	2.25 b	1.22 b	11.67 b	4.24 b	0.24 b	2.35 b
8	2.96 c	1.29 bc	13.32 cde	4.44 bc	0.32 c	2.34 b
12	3.92 d	1.37 cde	13.22 cd	4.41 bc	0.36 cd	2.35 b
16	3.88 d	1.31 bcd	13.41 def	4.52 cd	0.40 de	2.34 b
20	4.13 e	1.42 efg	12.93 c	4.58 cd	0.38 de	2.32 b
24	4.79 g	1.48 fg	13.68 efg	4.73 d	0.40 de	2.29 b
28	4.83 g	1.50 g	14.00 g	4.47 bc	0.45 f	2.33 b
32	4.63 f	1.40 def	13.81 fg	4.61 cd	0.41 ef	2.29 b
BLSD	0.14	0.10	0.43	0.26	0.05	0.07

For each column, means for treatments followed by the same letter do not differ significantly (BLSD = 0.05).

Table 16

Regression Equations and Correlation Coefficients Between the Evaluation Parameters and P Levels on Tifdwarf Bermudagrass Grown Under Field Conditions

Comparison	Regression Equation	r
P Levels(X) _vs_ VR(Y)	Y = 0.516 + 1.254 LOG(X)	0.936**
P Levels(X) _vs_ DW(Y)	Y = 1.062 + 0.115 LOG(X)	0.265**
P Levels(X) _vs_ CC(Y)	Y = 10.082 + 1.139 LOG(X)	0.594**
P Levels(X) _vs_ %P(Y)	Y = 0.136 + 0.085 LOG(X)	0.544**

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

Table 17

Regression Equations and Correlation Coefficients for Parameters Used to Evaluate P Treatment Effects on Tifdwarf Bermudagrass Grown Under Field Conditions

Comparison	Regression Equation	r
1) DW(X) _vs_ VR(Y)	Y = 1.366 + 1.779 (X)	0.588**
2) CC(X) _vs_ VR(Y)	Y = -2.604 + 0.490 (X)	0.726**
3) %P(X) _vs_ VR(Y)	Y = 1.66 + 5.76 (X)	0.622**
4) %P(X) _vs_ DW(Y)	Y = 0.960 + 0.959 (X)	0.311**
5) %P(X) _vs_ CC(Y)	Y = 9.840 + 8.500 (X)	0.620**

**Required r values for significance at the 1% level was 0.254 with 106 degrees of freedom.

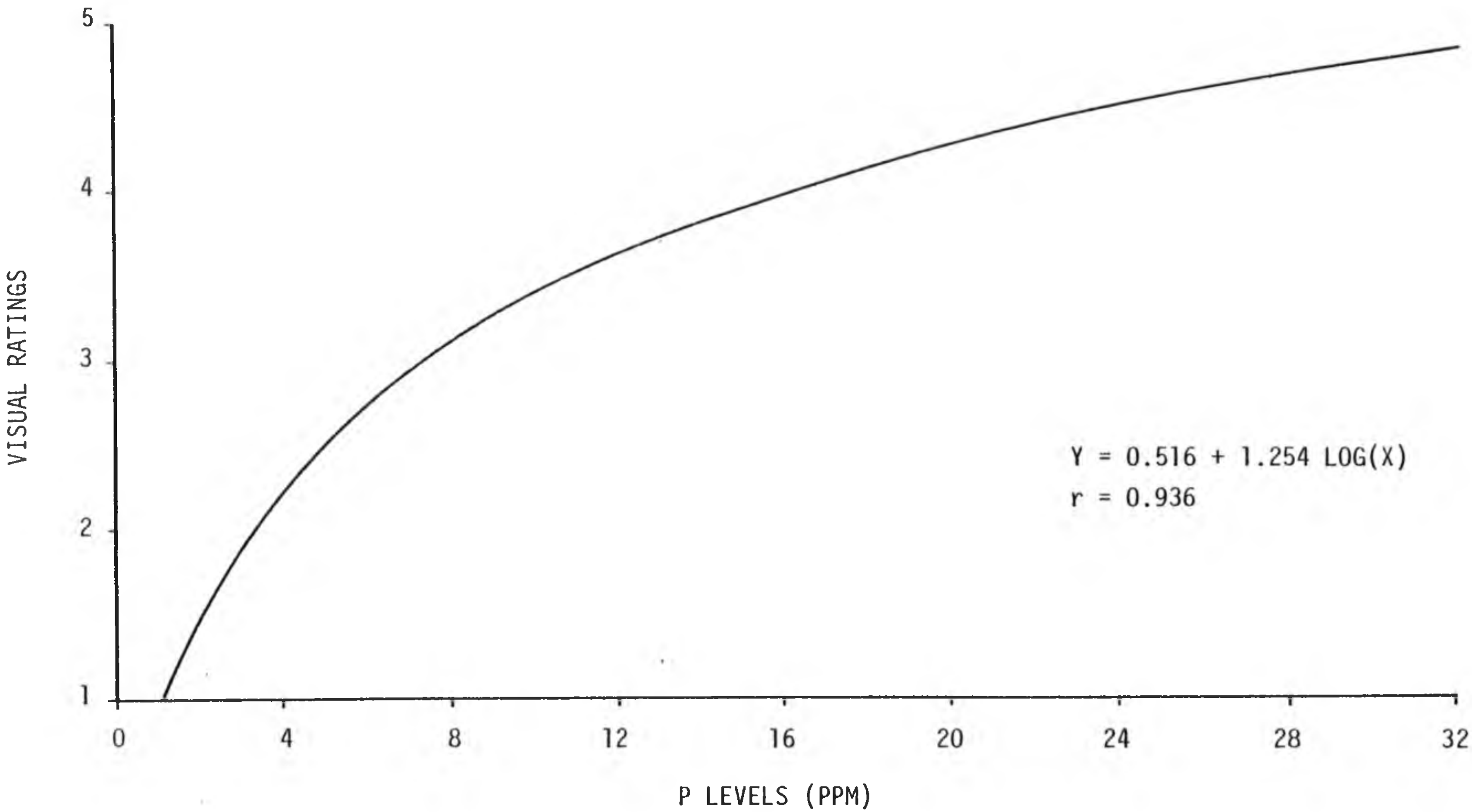

Figure 37. The effect of P levels on visual ratings.

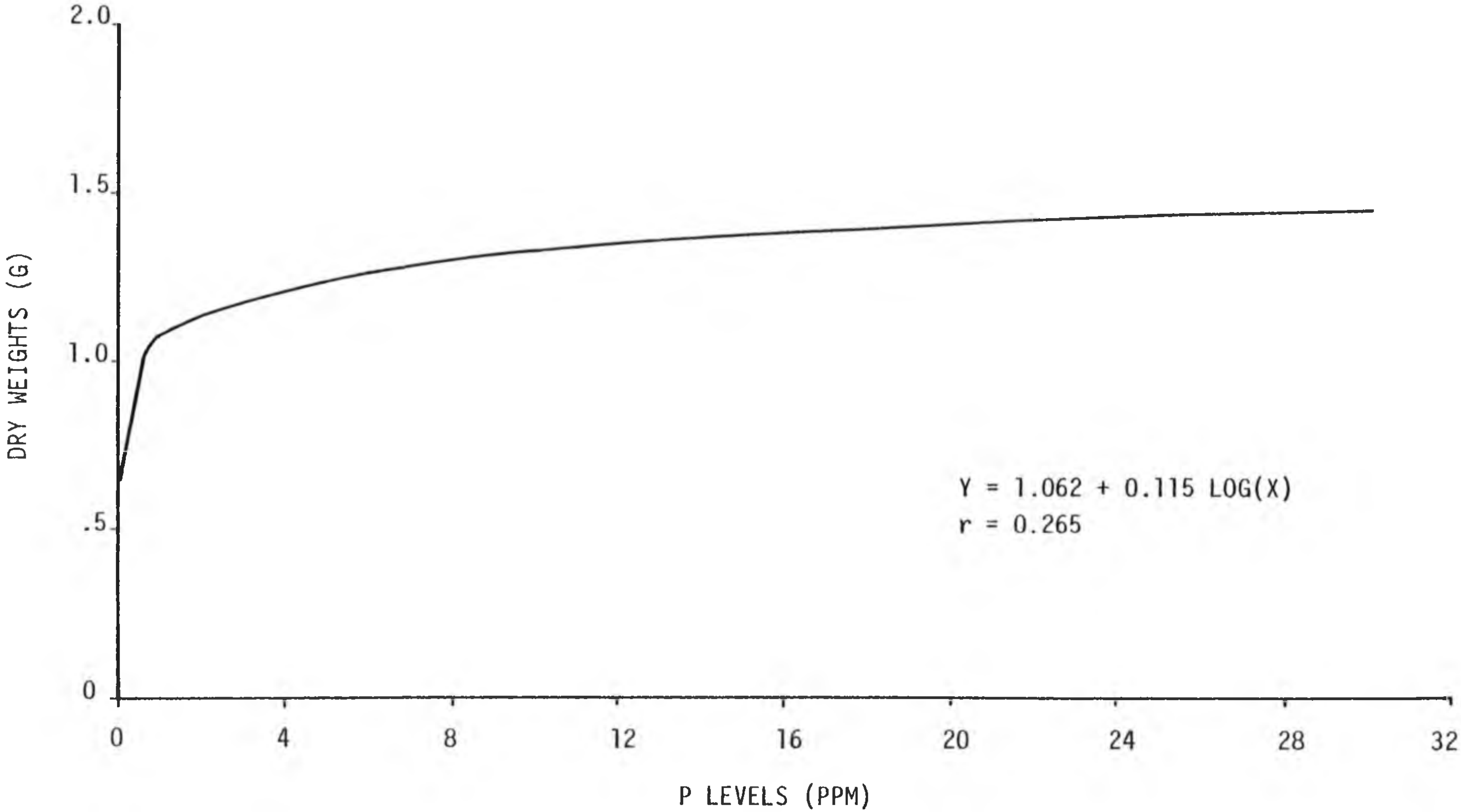

Figure 38. The effect of P levels on dry weight yields.

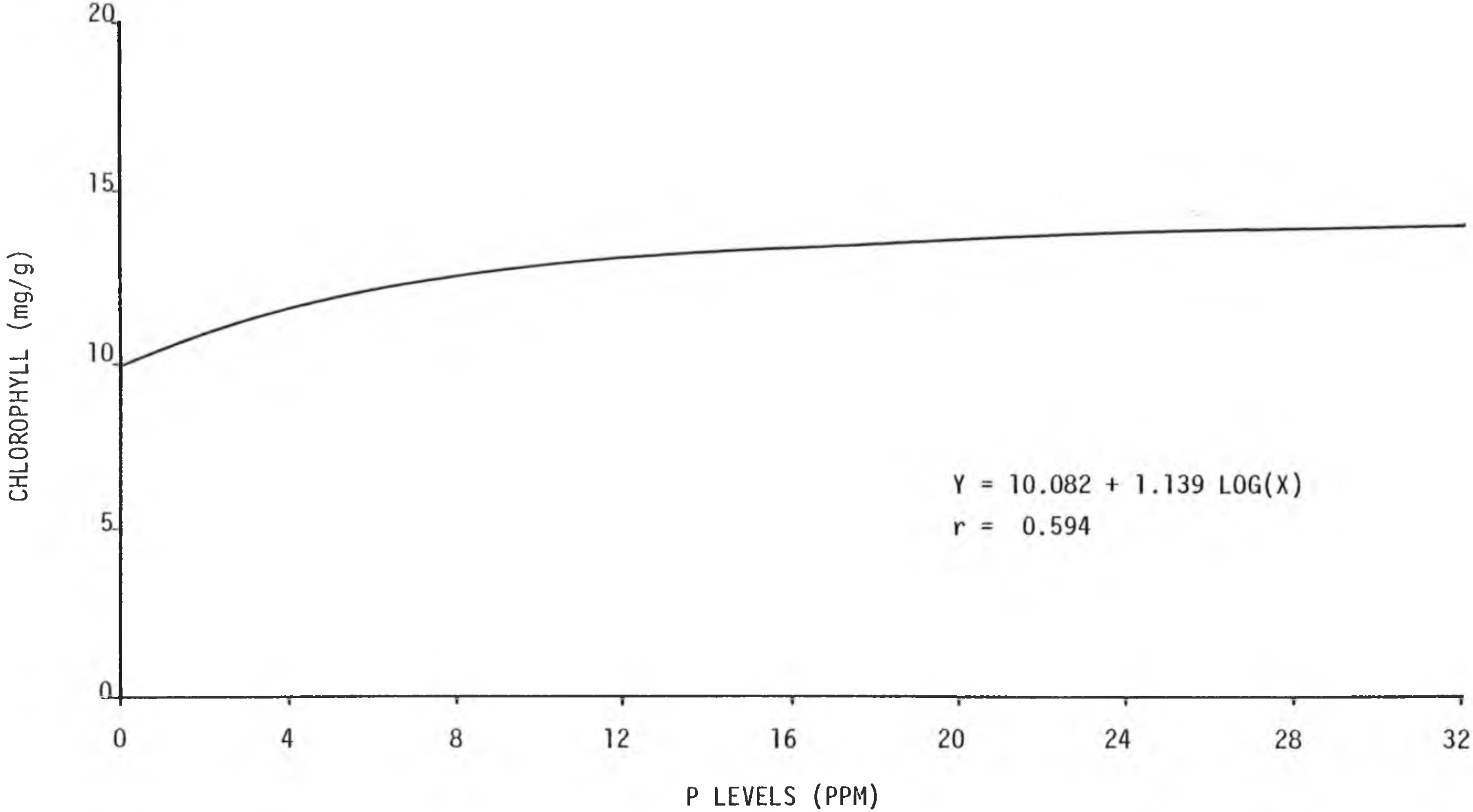

Figure 39. The effect of P levels on chlorophyll content.

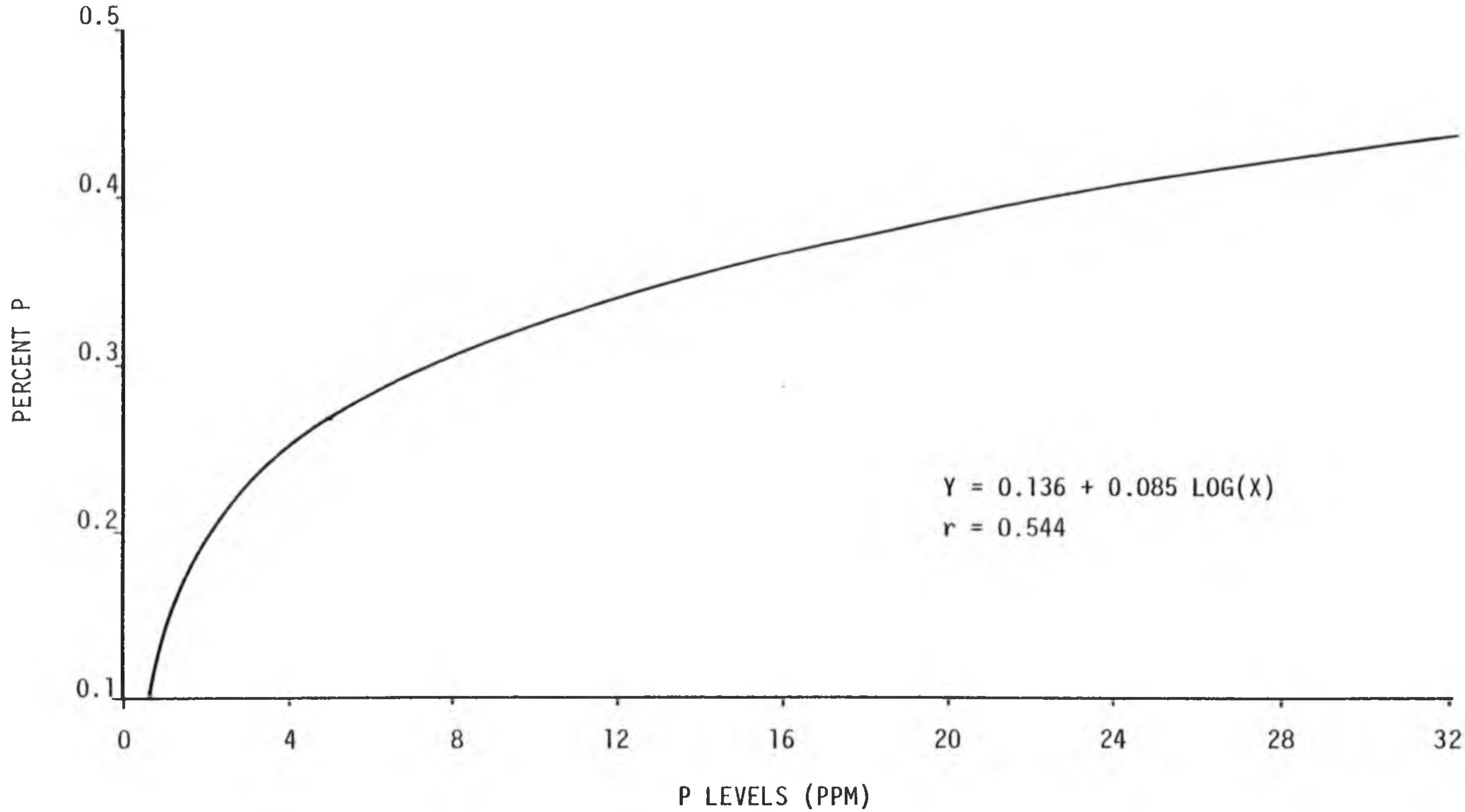

Figure 40. The effect of P levels on percent P in tissue.

Comparison of Parameters by Correlation and Regression

The primary parameters, VR, DW, CC, and %P, used to evaluate P treatment effects were correlated one with the other. Correlation coefficients and regression equations are presented in Table 17. All of the relationships were highly correlated at the 1% level, resulting in linear graphs with positive slopes (Figures 41 through 45).

The correlation of DW and VR was $r = 0.588$, $\underline{p} < .01$. Interpolation of the resultant regression line, shown in Figure 41, indicated that a DW of about 0.9 was associated with an "acceptable" VR of 3.

The highest correlation for all comparisons was obtained for CC with VR ($r = 0.726$, $\underline{p} < .01$). About 11 mg/g of chlorophyll was associated with an "acceptable" VR of 3.

The correlations of %P with VR, DW, and CC were all significant ($r = 0.622$, $r = 0.311$, and $r = 0.620$, respectively, at the .01 level). For the comparison between %P and VR, an "acceptable" VR was associated with a %P value of 0.23 (Figure 43).

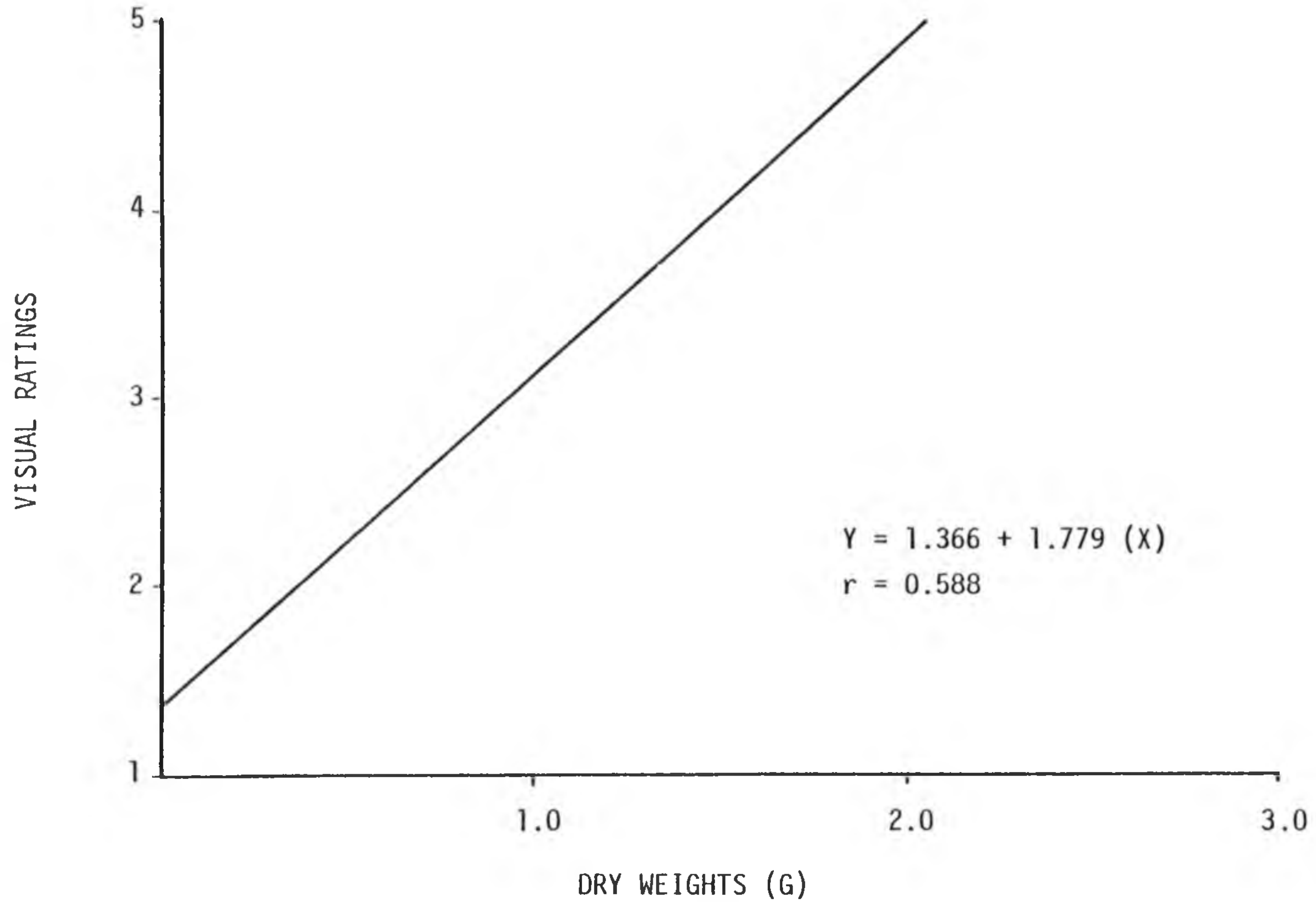

Figure 41. The relationship between visual ratings and dry weight yields.

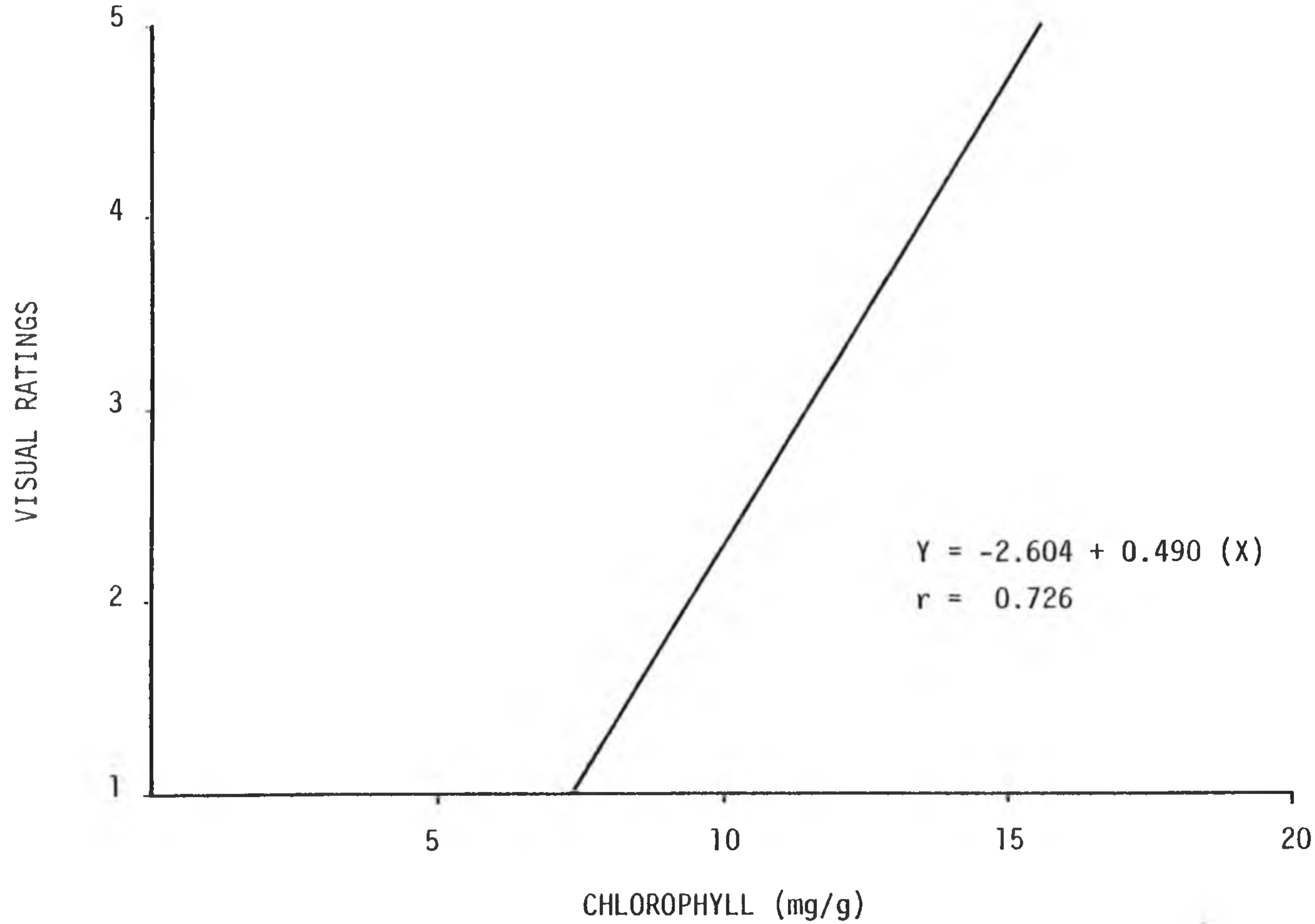

Figure 42. The relationship between visual ratings and chlorophyll content.

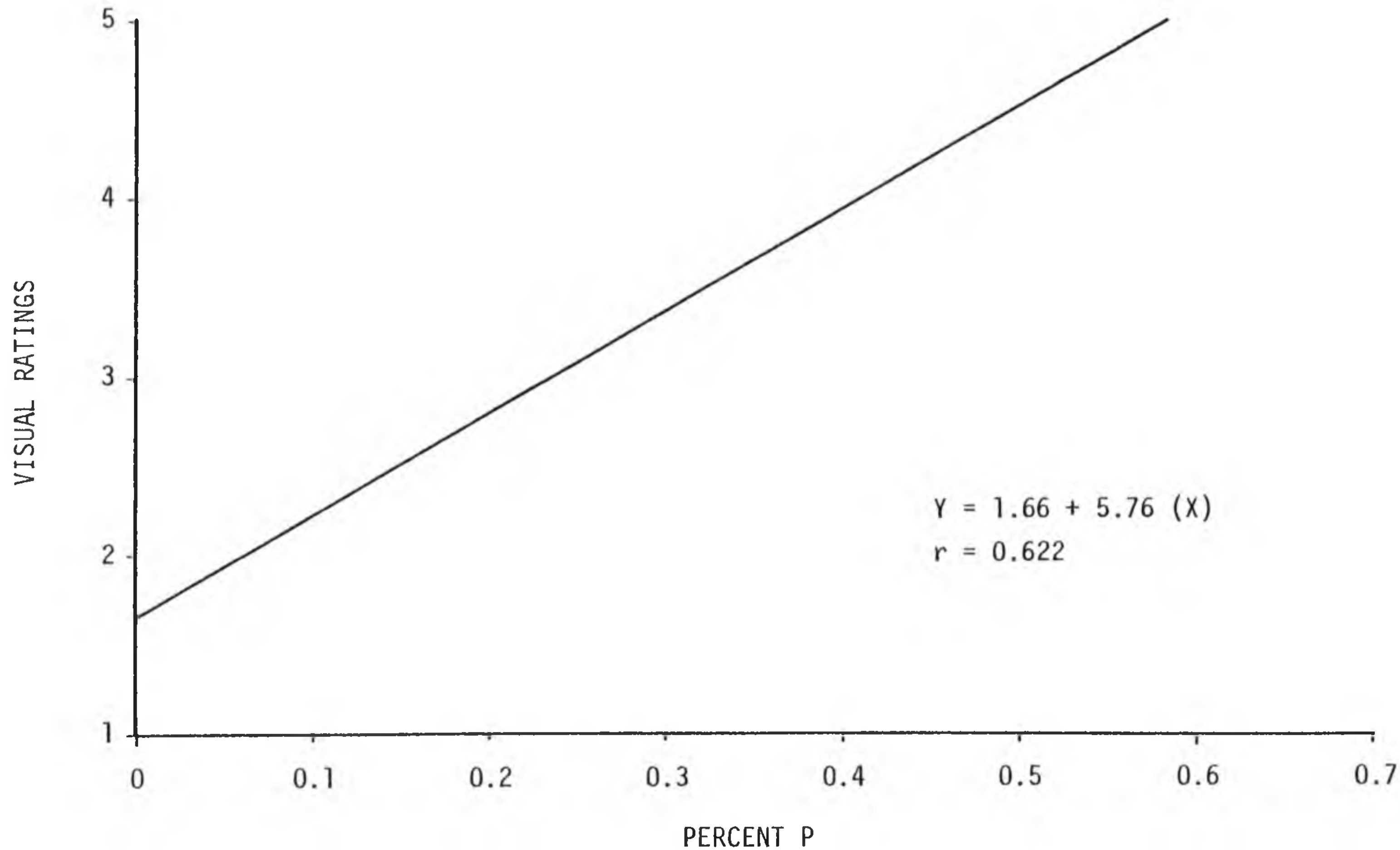

Figure 43. The effects of percent P on visual ratings.

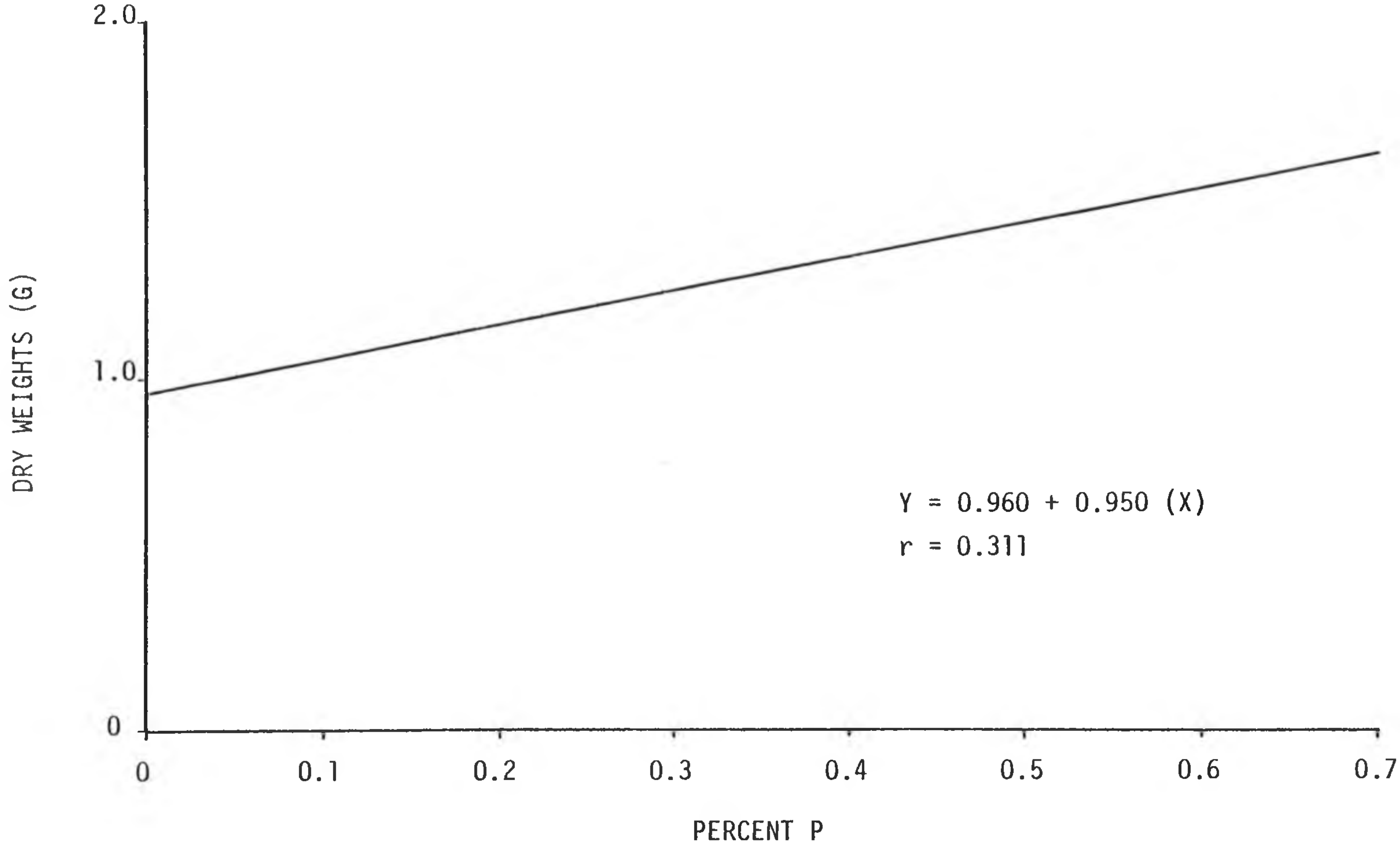

Figure 44. The effect of percent P on dry weight yields.

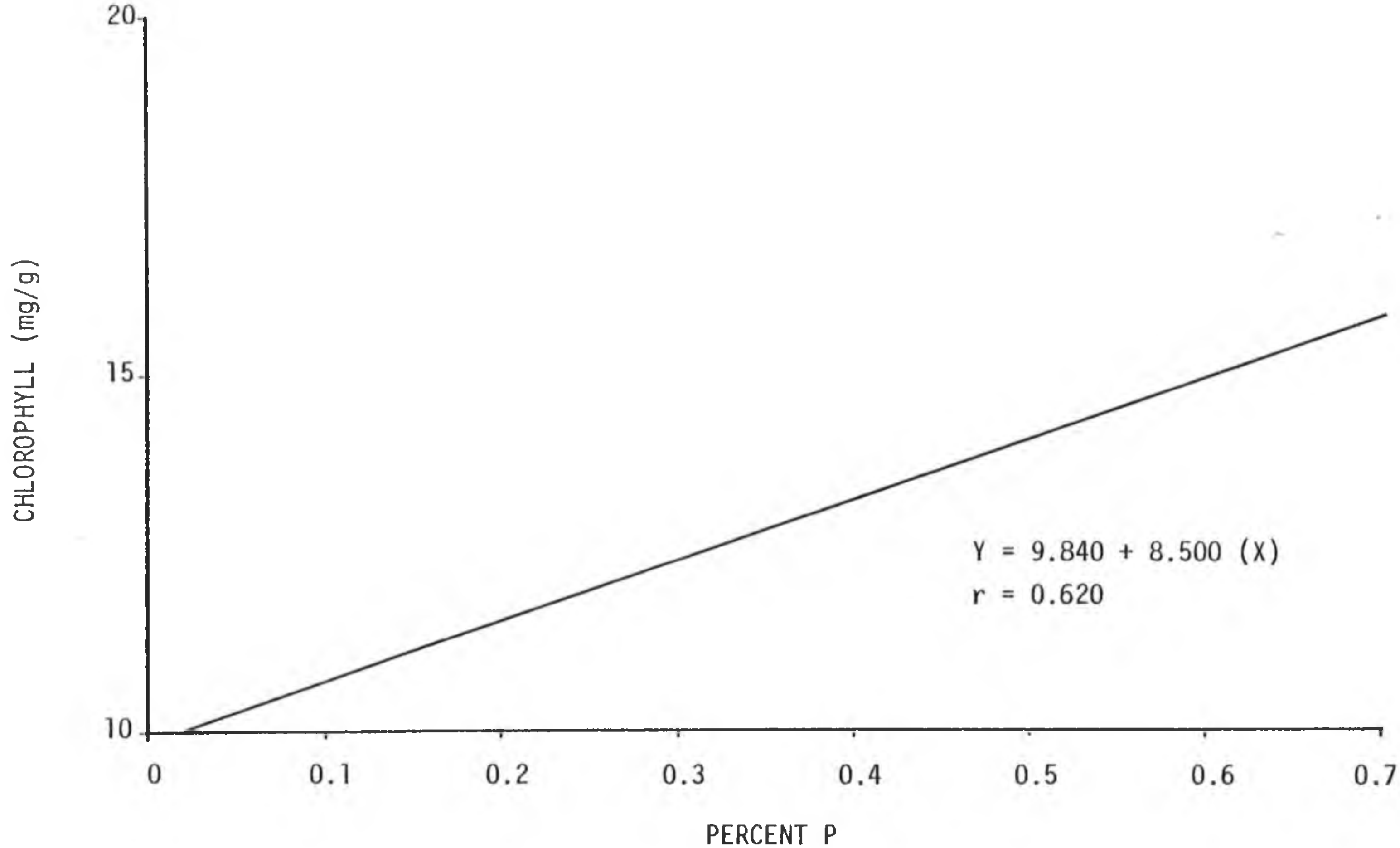

Figure 45. The effect of percent P on chlorophyll content.

Potassium Treatments

The main K treatment effects are presented in Table 18 as mean values. Parameters measuring VR, DW, and %K evidenced positive trends with increasing K levels. CC, %N, and %P values deviated from this trend, as will be reported later. Correlation and regression analysis were performed on the data obtained on the primary parameters, VR, DW, CC, and %K with the tabulated results presented in Table 19. Resultant curvilinear graphs of the relationships of parameters with K levels were consistently negatively accelerated.

VR effects. The VR means ranged from 1.67 to 4.33; these extremes were approximately $\pm$ 1.3 of the "acceptable" VR of 3. Turf pots treated with lower levels of K responded in similar fashion to those grown under glasshouse conditions. VR increased significantly with increasing levels of K levels up to 50 ppm, then leveled off between 75 and 125 ppm K. The highest mean was obtained at the 150 ppm level. Overall data for VR and K levels were significantly correlated ($r = 0.824$). The curve of VR plotted against K levels is presented in Figure 46. Distinct zones of deficiency, transition, and adequacy are easily demarcated at 12.5, 25, and 50 ppm, respectively.

DW effects. DW mean values ranged from 0.51 to 1.07. Significant increases in DW with increasing K levels were observed until 75 ppm, after which no significant increases were obtained. The overall correlation coefficient was 0.649. The curve plotted evidenced a zone of deficiency, transition, and adequacy; these were demarcated at 12.5, 25, and 150 (Figure 47).

CC effects. The range of CC means was from 12.99 to 13.76. The data indicate trends inconsistent to those for VR and DW. Although CC values increased between 0 and 50 ppm K, an overall decreasing trend was obtained. This observation was substantiated by a significantly negative correlation ($r = -0.251$, $p < .05$). Figure 48 illustrates the initial increase in CC followed by a gradual downward slope with higher K levels.

%K effects. Mean values of %K ranged from 1.17 to 2.11. Treatment means showed significantly increasing values with increments of K. The overall data for %K and K levels were significantly correlated ($r = 0.806$). Zones of deficiency, transition, and adequacy were demarcated at 6.25, 25, and 150 (Figure 49).

%N and %P effects. Supplementary Anova were performed on %N and %P data, resulting in no significant differences between their means with varying levels of P.

Table 18

Effects of K Levels on Visual Ratings of Turf Pots and Dried Weights, Chlorophyll Content, and Percent Composition of N, P, and K, Respectively, of Leaf Tissue of Tifdwarf Bermudagrass Grown Under Field Conditions

K Levels	VR	DW	CC	%N	%P	%K
0	1.67 a	0.51 a	12.99 a	4.26	0.46	1.17 a
6.25	2.29 b	0.74 b	13.40 abcd	4.12	0.42	1.27 b
12.50	2.83 c	0.79 b	13.91 d	4.26	0.41	1.46 c
25.00	3.29 d	0.77 b	13.59 bcd	4.42	0.51	1.66 d
50.00	3.79 e	0.88 c	13.76 cd	4.12	0.46	1.82 e
75.00	4.00 ef	1.01 de	13.02 a	4.24	0.45	1.92 f
100.00	4.08 fg	0.99 d	13.29 abc	4.25	0.46	1.94 f
125.00	4.08 fg	1.01 de	13.17 ab	4.32	0.43	2.01 g
150.00	4.33 g	1.07 e	13.04 ab	4.07	0.46	2.11 h
BLSD	0.26	0.07	0.57	----	----	0.03

For each column, means for treatments followed by the same letter do not differ significantly (BLSD = 0.05).

Table 19

Regression Equations and Correlation Coefficients Between the Evaluation Parameters and K Levels on Tifdwarf Bermudagrass Grown Under Field Conditions

Comparison	Regression Equation	r
K Level(X) vs VR(Y)	Y = 1.253 + 0.617 LOG(X)	0.824**
K Level(X) vs DW(Y)	Y = 0.509 + 0.105 LOG(X)	0.649**
K Level(X) vs CC(Y)	Y = 14.081 - 0.182 LOG(X)	-0.251*
K Level(X) vs %K(Y)	Y = 0.827 + 0.249 LOG(X)	0.806**

*Required r value for significance at the 5% level was 0.195 with 106 degrees of freedom.

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

Table 20

Regression Equations and Correlation Coefficients for Parameters Used to Evaluate K Treatment Effects on Tifdwarf Bermudagrass Grown Under Field Conditions

Comparison	Regression Equation	r
1) DW(X) vs VR(Y)	Y = 0.802 + 2.984 (X)	0.636**
2) CC(X) vs VR(Y)	Y = 4.779 - 0.105 (X)	-0.084
3) %K(X) vs VR(Y)	Y = 0.400 + 1.745 (X)	0.665**
4) %K(X) vs DW(Y)	Y = 0.195 + 0.391 (X)	0.698**
5) %K(X) vs CC(Y)	Y = 13.514 - 0.096 (X)	-0.047

**Required r value for significance at the 1% level was 0.254 with 106 degrees of freedom.

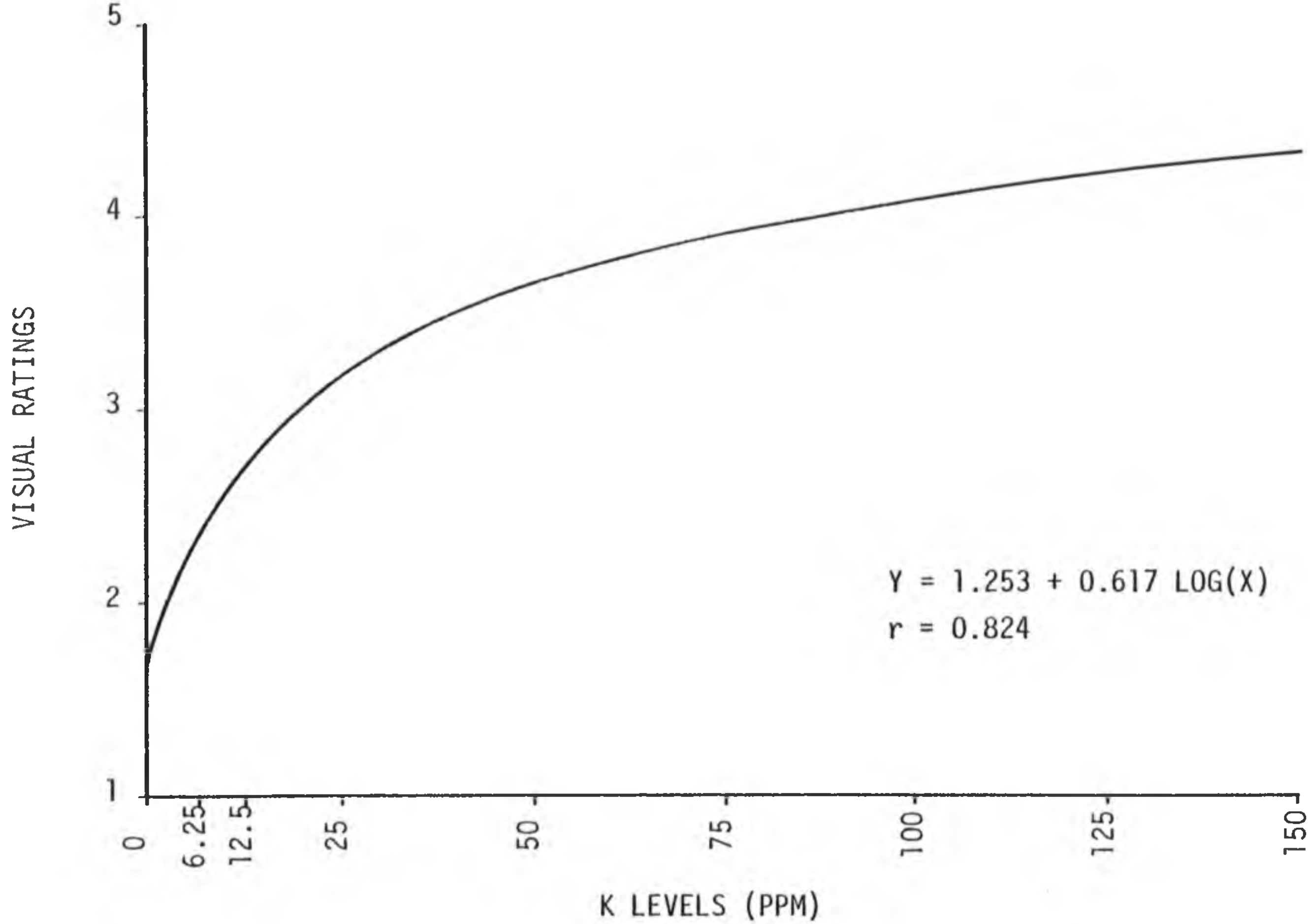

Figure 46. The effect of K levels on visual ratings.

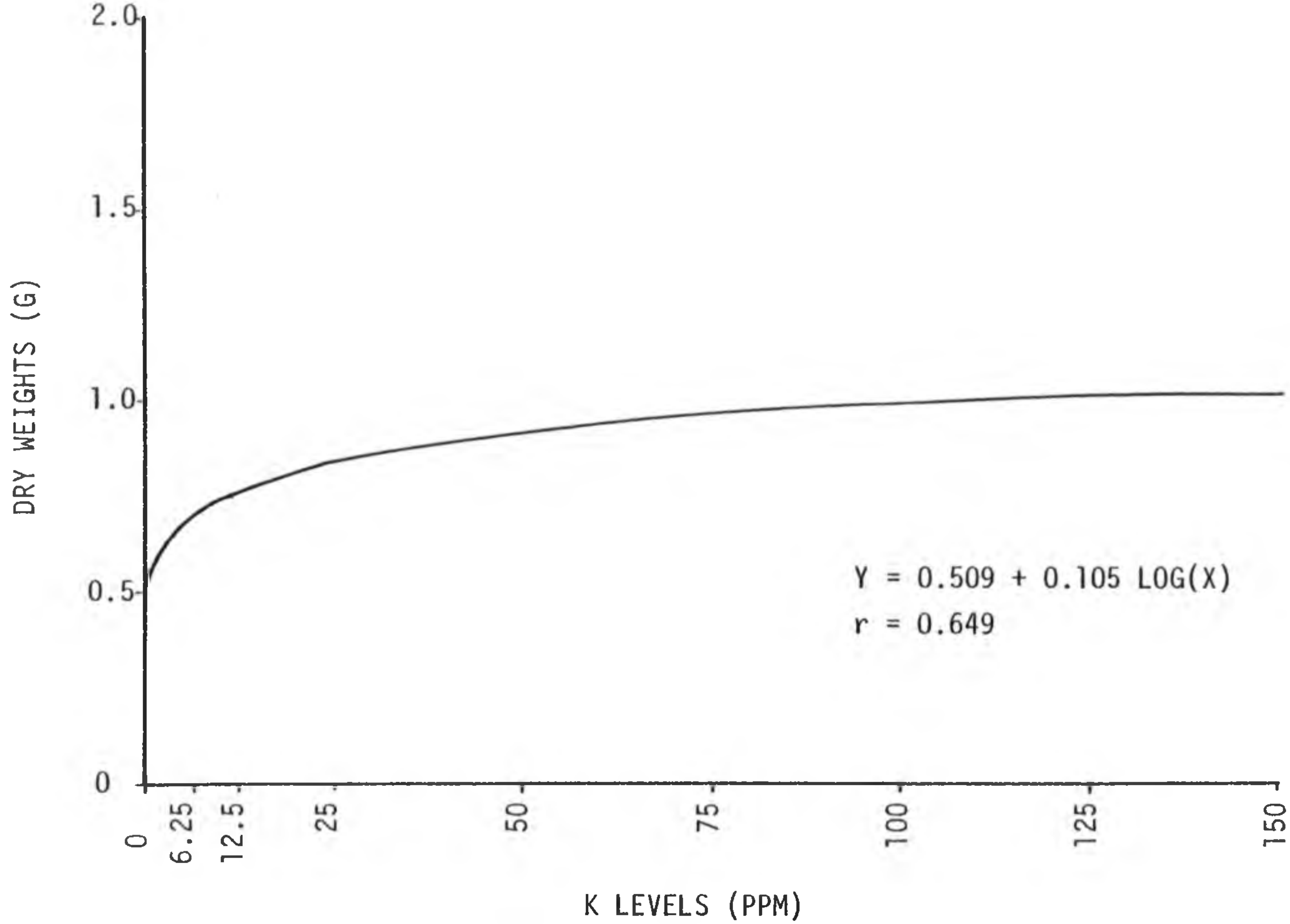

Figure 47. The effect of K levels on dry weight yields.

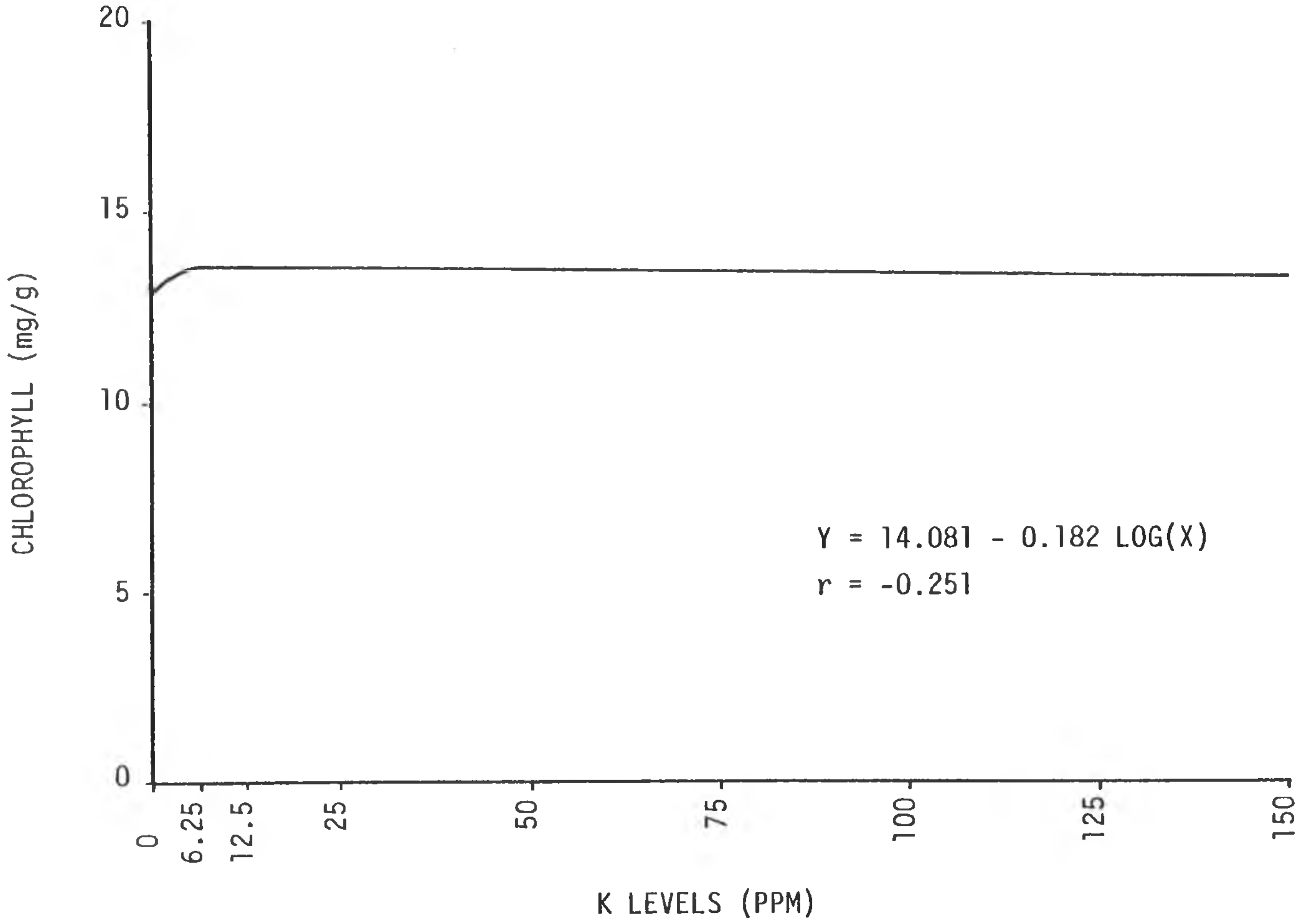

Figure 48. The effect of K levels on chlorophyll content.

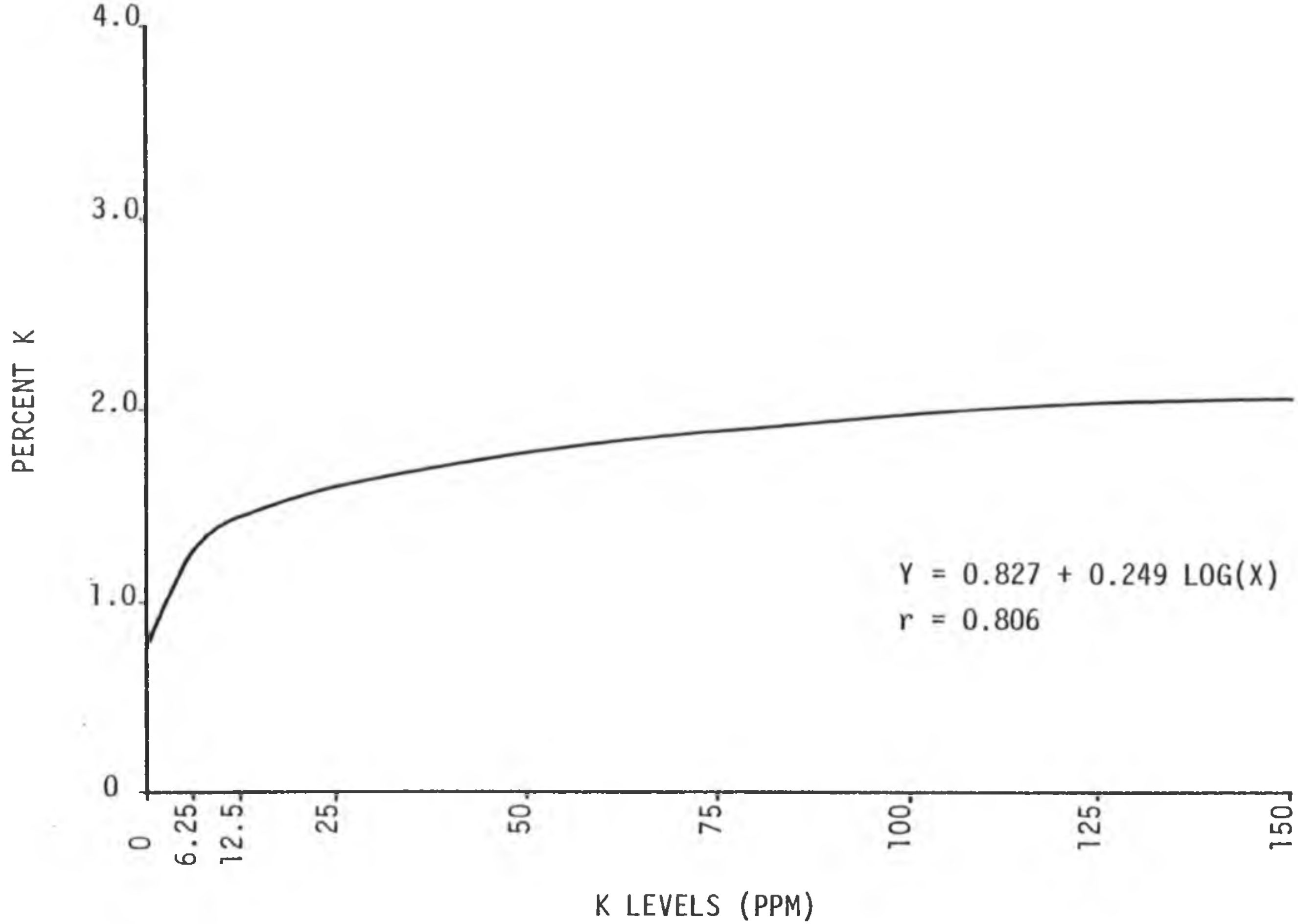

Figure 49. The effect of K levels on percent K in tissue.

Comparison of Parameters by Correlation and Regression

The primary parameters, VR, DW, CC, and %K, used in evaluating %K treatment effects did not result in significant correlations. Both comparisons involving CC deviated from all previous trends, as will be discussed later. Correlation coefficients and regression are presented in Table 20, and the graphical relationships of these relationships are illustrated in Figures 50 through 54.

A highly correlated relationship resulted between DW and VR ($r = 0.636$, $p < .01$). Interpolation of the resultant regression shown in Figure 50 indicated that about 0.75 g was associated with an "acceptable" VR of 3.

CC compared with VR resulted in a negative correlation which was not significant ($r = -0.084$, Figure 51).

The relationship between %K and VR resulted in a high correlation compared to other comparisons made ($r = 0.698$, $p < .01$). Interpolation of the resultant regression graph indicated that a %K value of 1.5 was associated with a VR of 3.

The correlation of %K with DW resulted in the highest of all comparisons ($r = 0.698$), while the relationship between %K and CC was, as that for CC and VR, a negative one, which was not significant ($r = -0.047$).

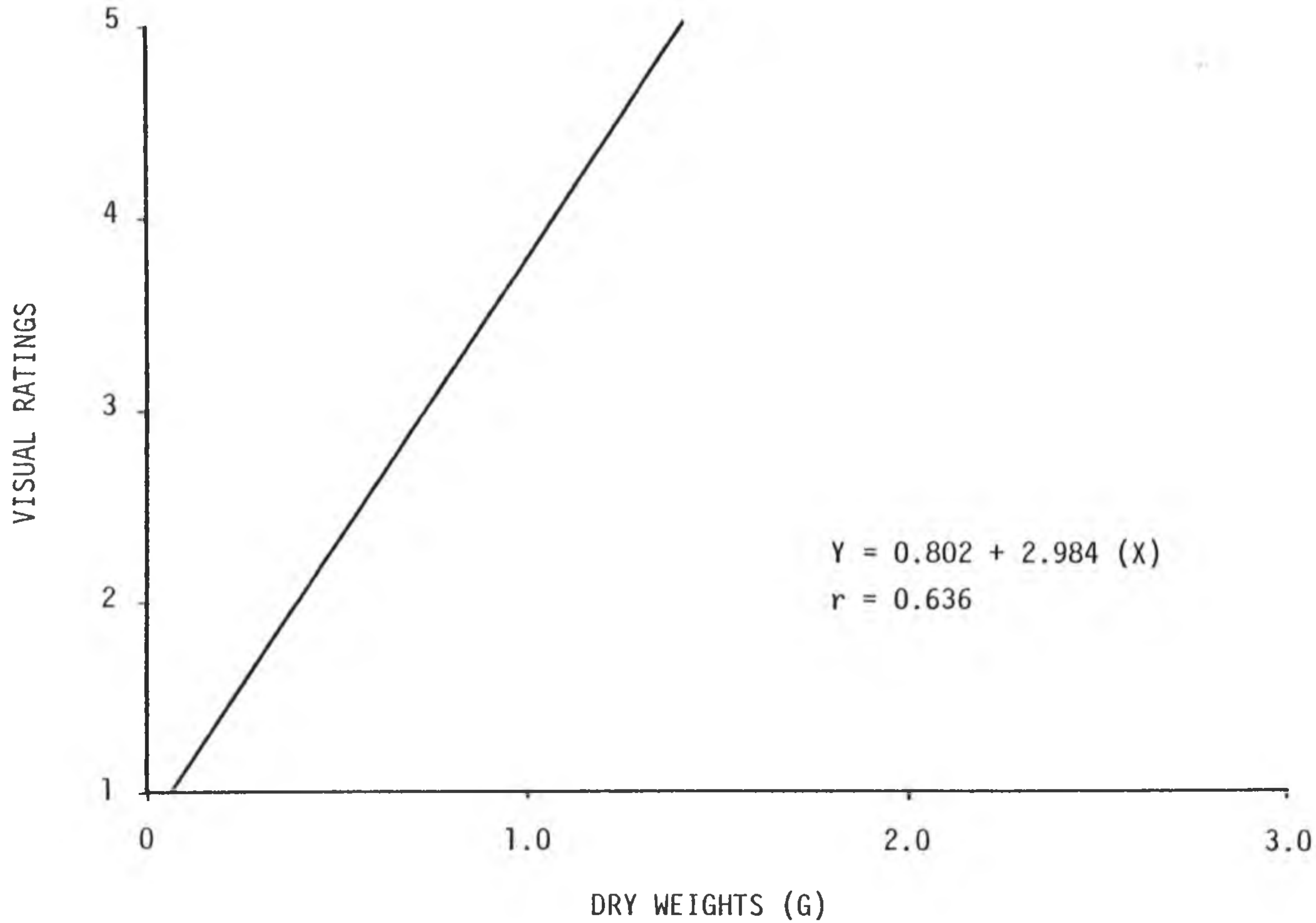

Figure 50. The relationship between visual ratings and chlorophyll content.

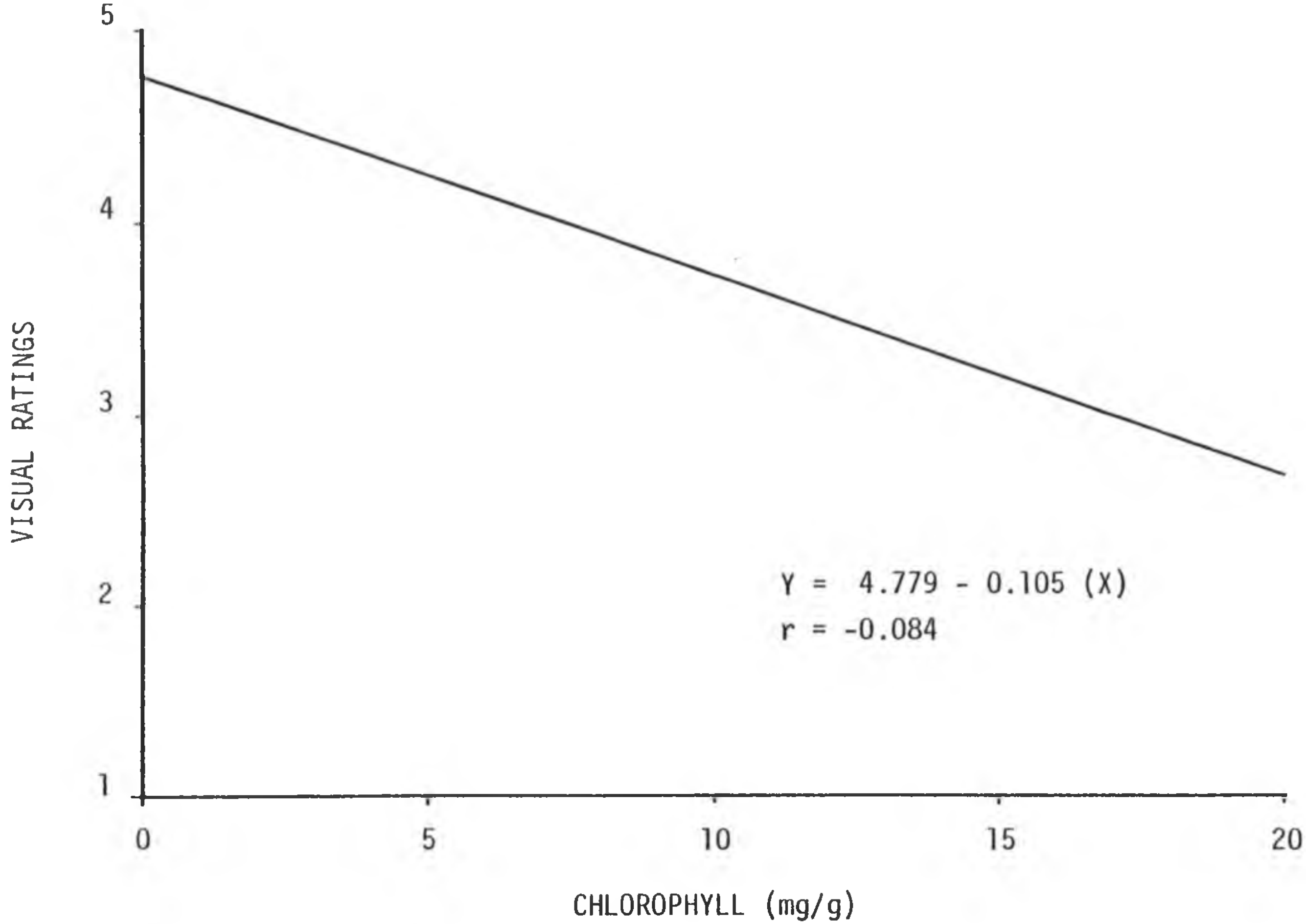

Figure 51. The relationship between visual ratings and chlorophyll content.

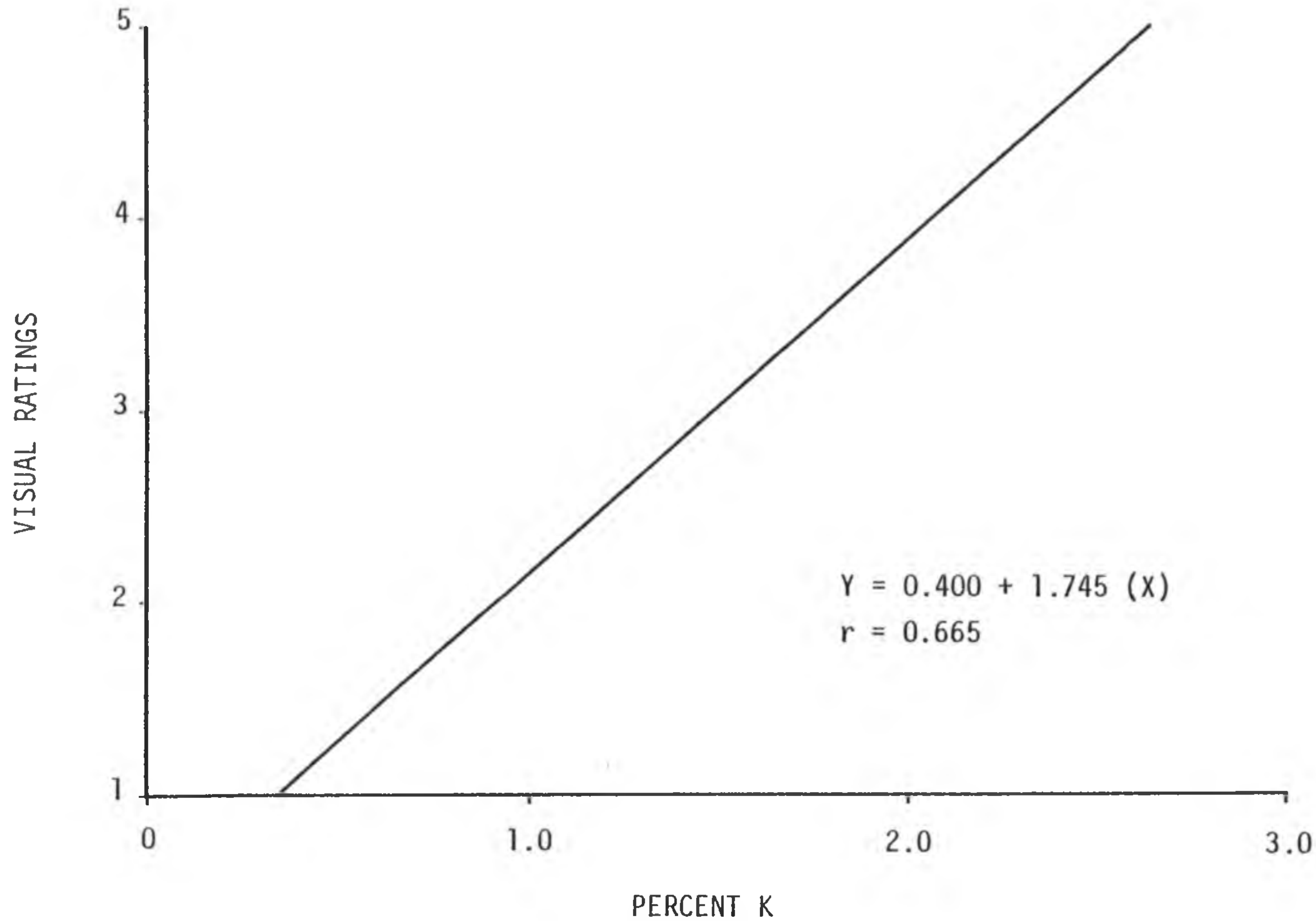

Figure 52. The effect of percent K on visual ratings.

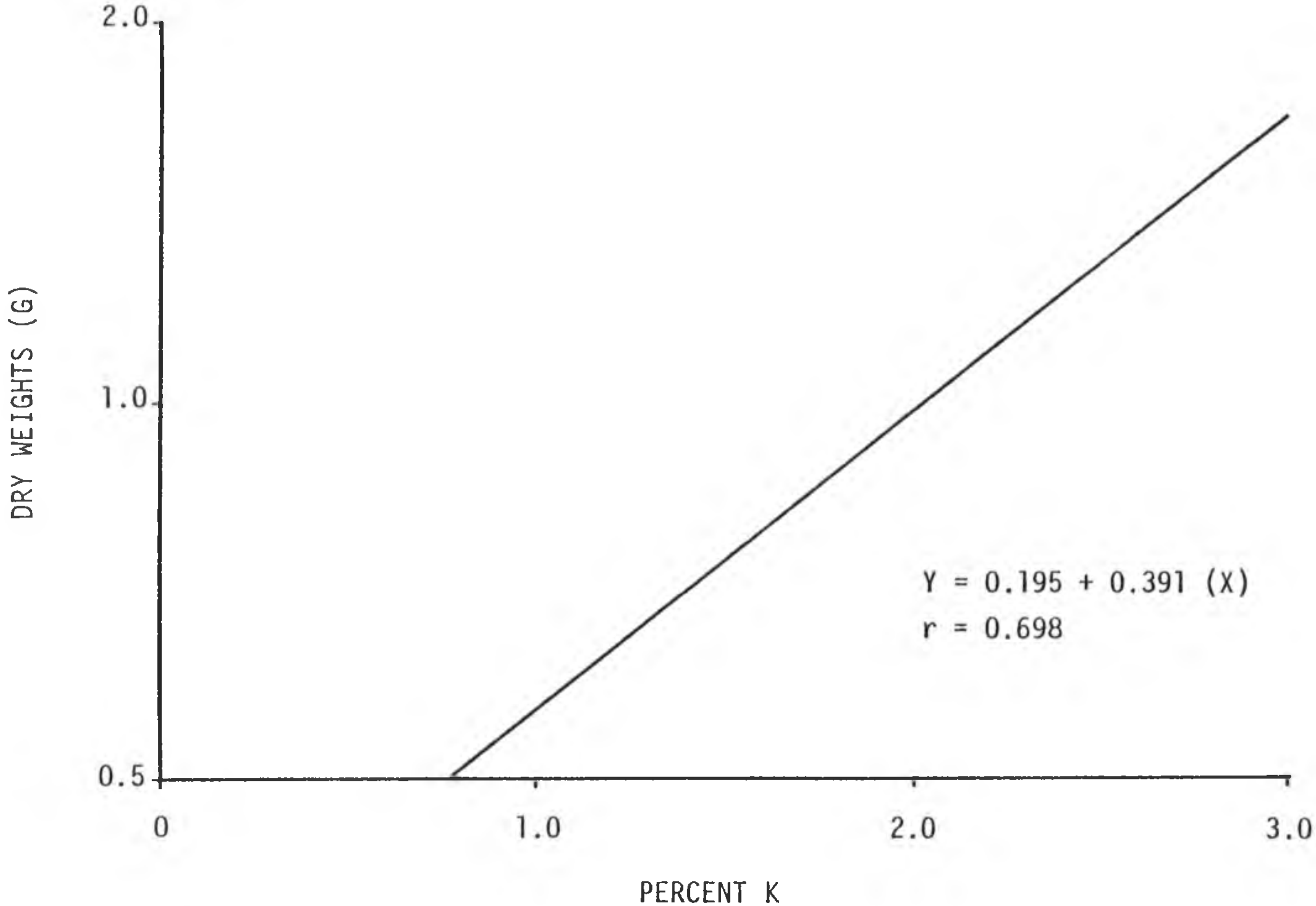

Figure 53. The effect of percent K on dry weight yields.

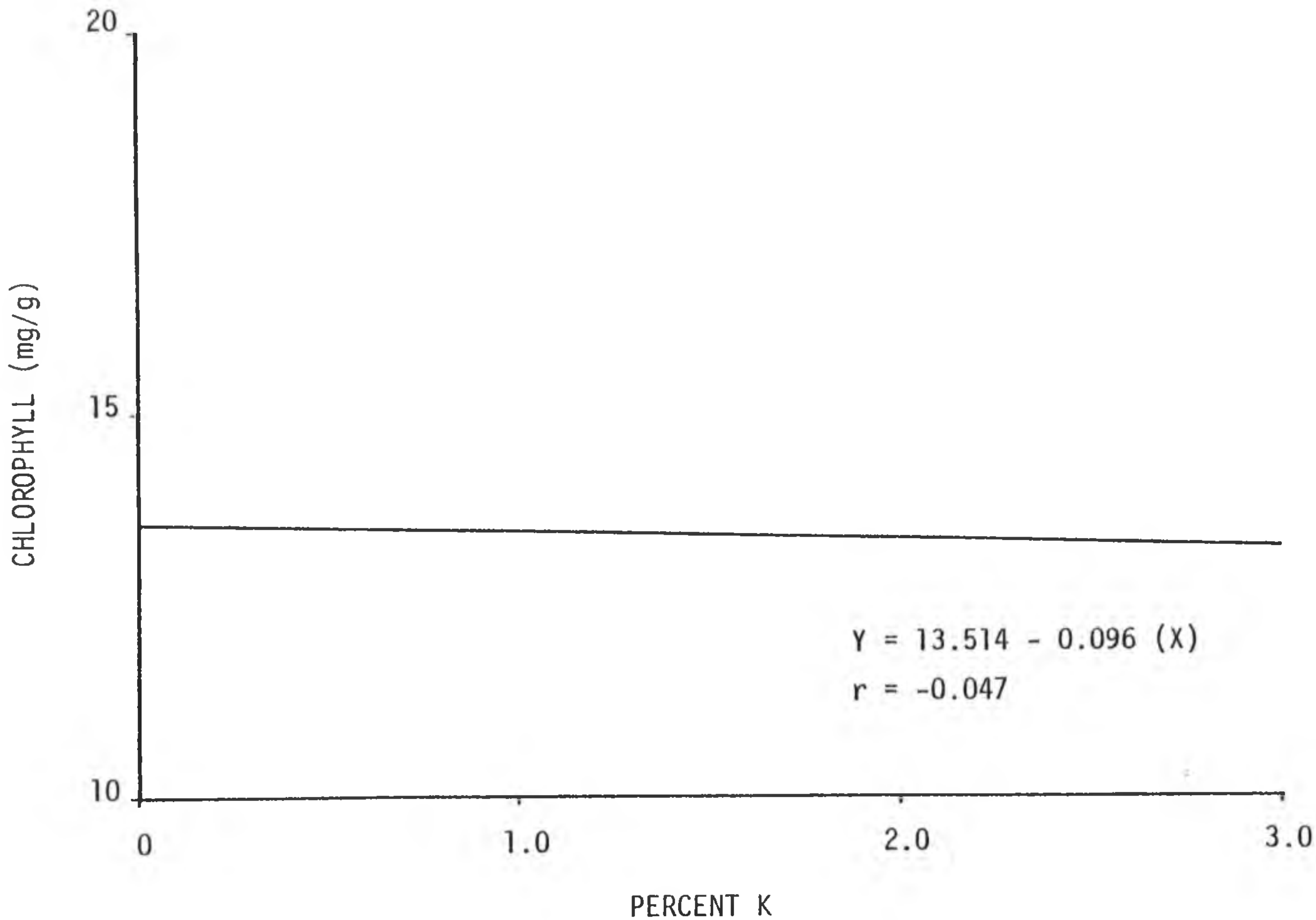

Figure 54. The effect of percent K on chlorophyll content.

Experiment III: Combination Treatments in Glasshouse

The effects of the combination of N, P, and K on VR, DW, CC, and percent composition of N, P, and K are summarized as mean values in Table 21. Of the six parameters measured, only VR and %N showed significant interaction effects, as will be reported later.

VR effects. The main effect of increasing P levels was a significant increase in VR. No significant effects were obtained for increasing K levels on VR. VR means for main effects are presented in Table 21. A narrow range of VR means, 4.54 to 4.96, was obtained for the interaction effects; turf pots were consistently of luxuriant quality. The highest VR mean was obtained with a high P level (12 ppm) combined with a medium K level (75 ppm) and a high K level (100 ppm), respectively; the lowest, with a low P level (4 ppm). The interactions were significant (Anova, $p < .01$), indicating that the effect of increased P levels on VR was not equally great for turf pots treated with different levels of K. The interactions are presented graphically in Figure 55. The most notable interactions occurred between 50 and 75 ppm K. With P held constant at 4 ppm, VR sharply decreased, while for P held at 8 ppm and 12 ppm, VR sharply increased. Though evident beyond the 75 ppm K level, the interactions were not as pronounced. With P held at 4 ppm, VR increased with increasing K levels, while for P held at 8 ppm, VR decreased. For P held at 12 ppm, VR remained constant.

%N effects. The main effects of increasing P and K levels on %N in leaf tissue were not significant. The interactions between P and K levels on %N was, however, significant. A narrow range %N mean values, 4.51 to 4.84, was obtained (Table 21). Regardless of treatment then,

%N was consistently high. The highest %N mean value was obtained for the treatment combining low P (4 ppm) with low K (50 ppm); the lowest, for low P and high K (100 ppm). The interactions were significant, indicating that the effect of increased P levels on %N was not equally great for turf pots treated with varying levels of K. The interactions are presented graphically in Figure 56. The most notable interaction occurred between 50 and 75 ppm K and 75 and 100 ppm K, respectively. Between 50 and 75 ppm, %N sharply decreased with increasing K levels with P being held constant at 4 ppm, while for P held at 8 and 12 ppm, %N as constant. Between 75 and 100, %N continued to decrease with increasing K levels for P held at 4 ppm, while %N increased with increasing K levels for P at 8 ppm and decreased with increasing K levels for P at 12 ppm.

DW, CC, %P and %K effects. The interaction of P and K levels were not significant for these four parameters. Some significant main effects were observed for CC, %P, and %K, but not with DW. Increasing K levels resulted in decreased CC; P levels, on the other hand, had no significant effect. With increased P levels, %P increased, while with increased K levels, %K increased.

TABLE 21

Overall Means of Comination Treatments

Treatment Cominations	VR	DW	CC	%N	%P	%K
4 x 50	4.83 abc	1.09	15.79	4.84 a	0.48	1.99
4 x 75	4.54 e	1.06	14.93	4.69 bc	0.46	2.28
4 x 100	4.63 de	1.12	14.74	4.51 d	0.45	2.63
8 x 50	4.63 de	0.99	15.65	4.68 bc	0.54	2.00
8 x 75	4.92 ab	1.00	14.79	4.65 c	0.54	2.33
8 x 100	4.79 bcd	1.06	15.29	4.77 abc	0.48	2.55
12 x 50	4.71 cd	1.07	15.78	4.79 ab	0.56	2.16
12 x 75	4.96 a	1.07	15.67	4.78 abc	0.54	2.39
12 x 100	4.96 a	1.07	14.95	4.73 abc	0.54	2.69
	0.17	----	----	0.16	----	----

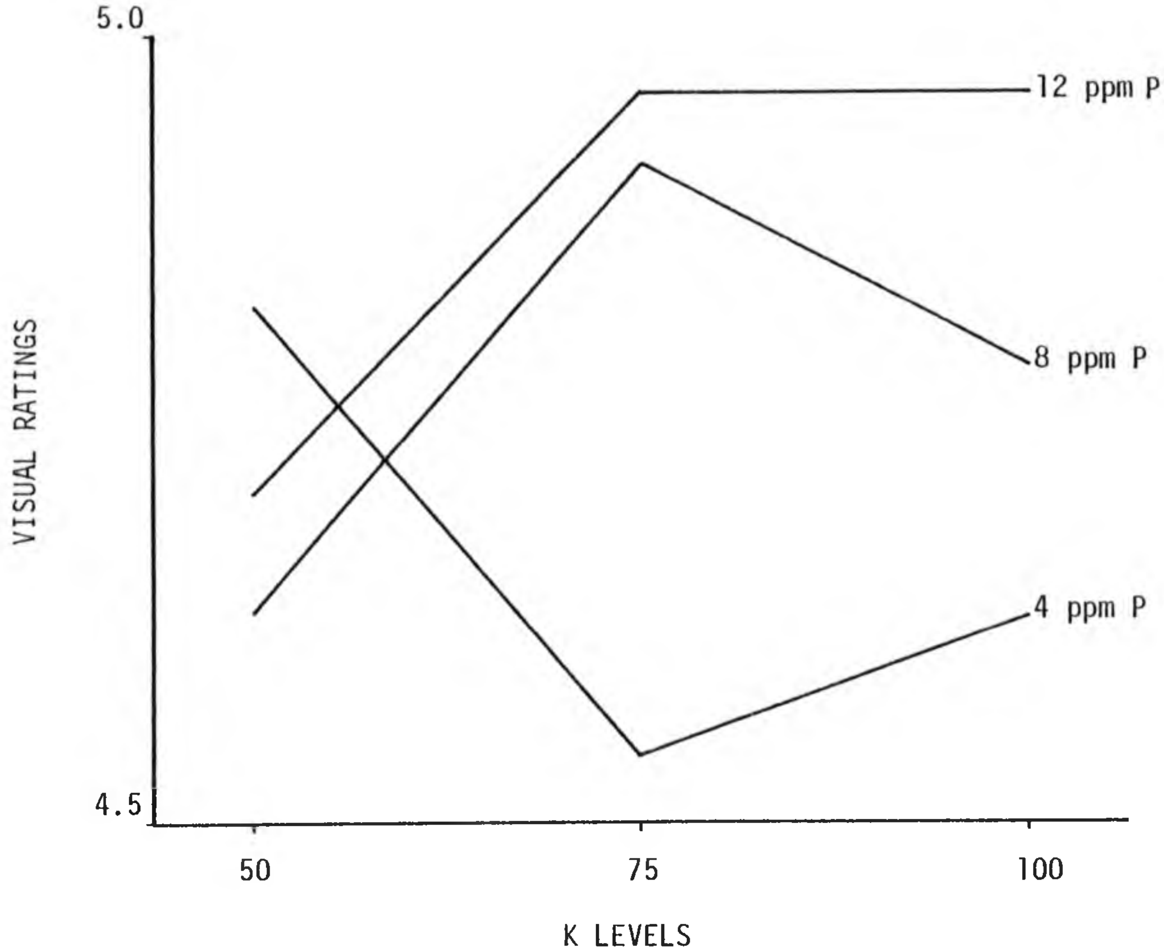

Figure 55. The effects of varying P and K levels on visual ratings. (BLSD = .05)

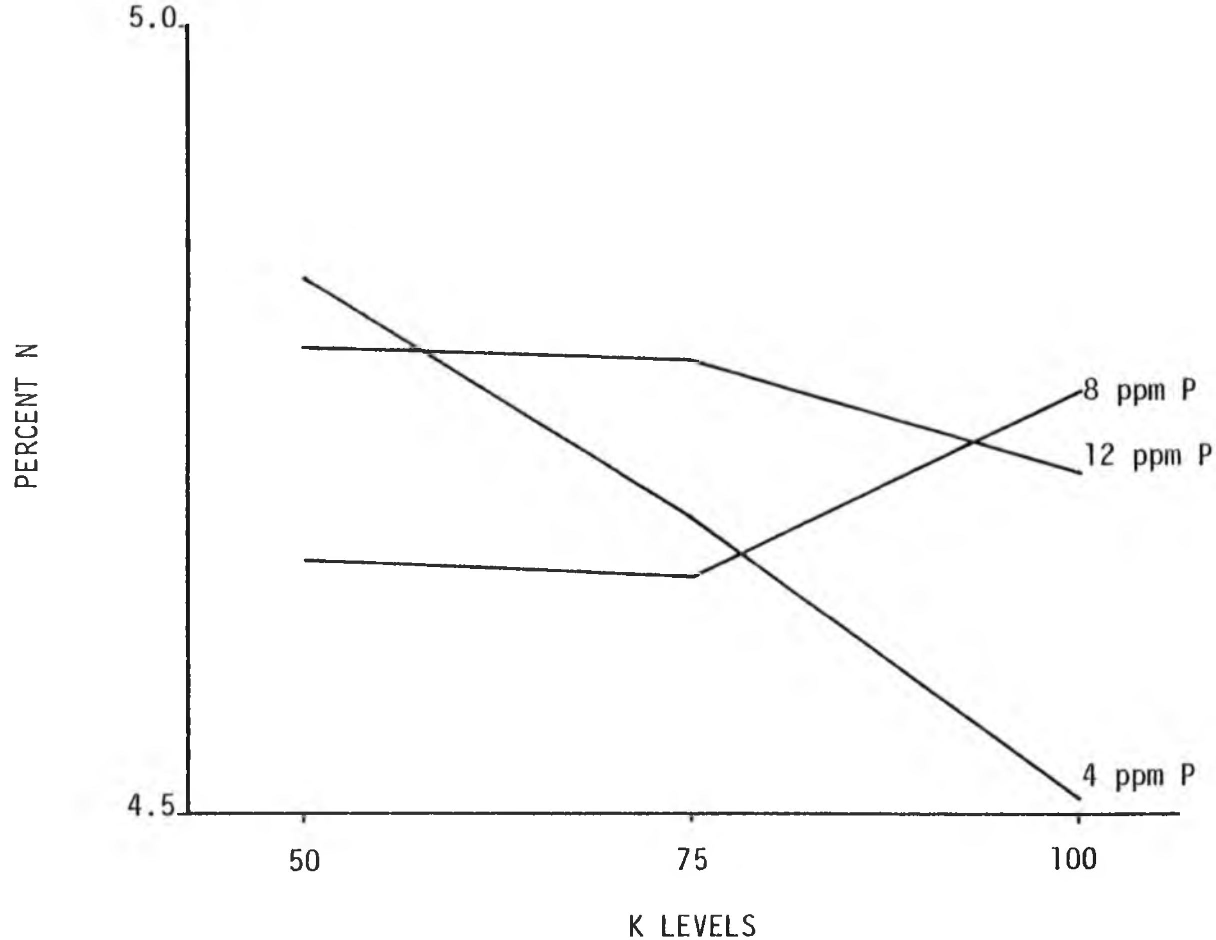

Figure 56. The effects of varying P and K levels on percent N in tissue. (BLSD = .05)

Field Monitoring Studies

January 5 - February 2, 1979: For all observed greens at both the Waialae Country Club (WCC) and the Oahu Country Club (OCC), the greatest fluctuation in % nutrient in the turf clippings was observed for N; %P and %K in comparison were relatively stable for all dates during this time period. This observation may be attributed to greater sensitivity on the part of %N in turf tissue to uncontrolled environmental conditions. As examples, note the N fluctuations observed for January 19, 21, and 28, all dates which had heavy rainfall in common (Figure 57). In spite of the seemingly drastic fluctuations experienced for such dates, the %N content values for the turf leaves were for the most part within the optimum nutrient range determined in Experiments I and II for N at WCC, while at OCC, the %N content was in general consistently above this range. (Five %N was determined to be the upper limit of the optimum nutrient range for N). For both WCC and OCC, %P content was found to be generally in excess of the determined 0.4% upper limit. Data for %K differed at both locations; at OCC, %K was found to be in excessively high amounts, indicating extreme luxury consumption, and at WCC, the %K content was found to be within the optimum nutrient range (1.5 - 2.0%), except for the latter dates at which time the %K content dipped below this range (Figure 65). Based on the nutrient ranges for optimum growth obtained from Experiment I and II, remedial fertilization programs were recommended and put into practice.

WCC: March 7 - April 15, 1979 and OCC: March 14 - April 13, 1979: Follow-up monitoring studies about one month later revealed consistently high %N content values which were fluctuating more widely than the first field monitoring dates for both OCC and WCC. It can again only be speculated as to why an elevation of %N values occurred. Perhaps, as mentioned in the discussion section for Experiment II, this outcome may have been due to greater amount of stolon and other organic matter decay accelerated by the heavy rainfall of that period, influencing the amount of N available as the result of biological consumption and in turn resulting in luxury consumption of N by the turfgrass. %P in the leaves remained for the most part constant across the dates of this period and unchanged for OCC from the previous month's data; at WCC, however, a small reduction in %P was observed in the direction of the optimum nutrient range. At OCC, a substantial drop in %K was observed (Figure 69), while at WCC, an increase in %K was observed (Figure 61); both changes were in the direction toward the optimum nutrient level. Although following the fluctuations of %N, VR remained within the optimum range (3-4) despite the reduction of N, P, and K, as well as the increase in K for OCC.

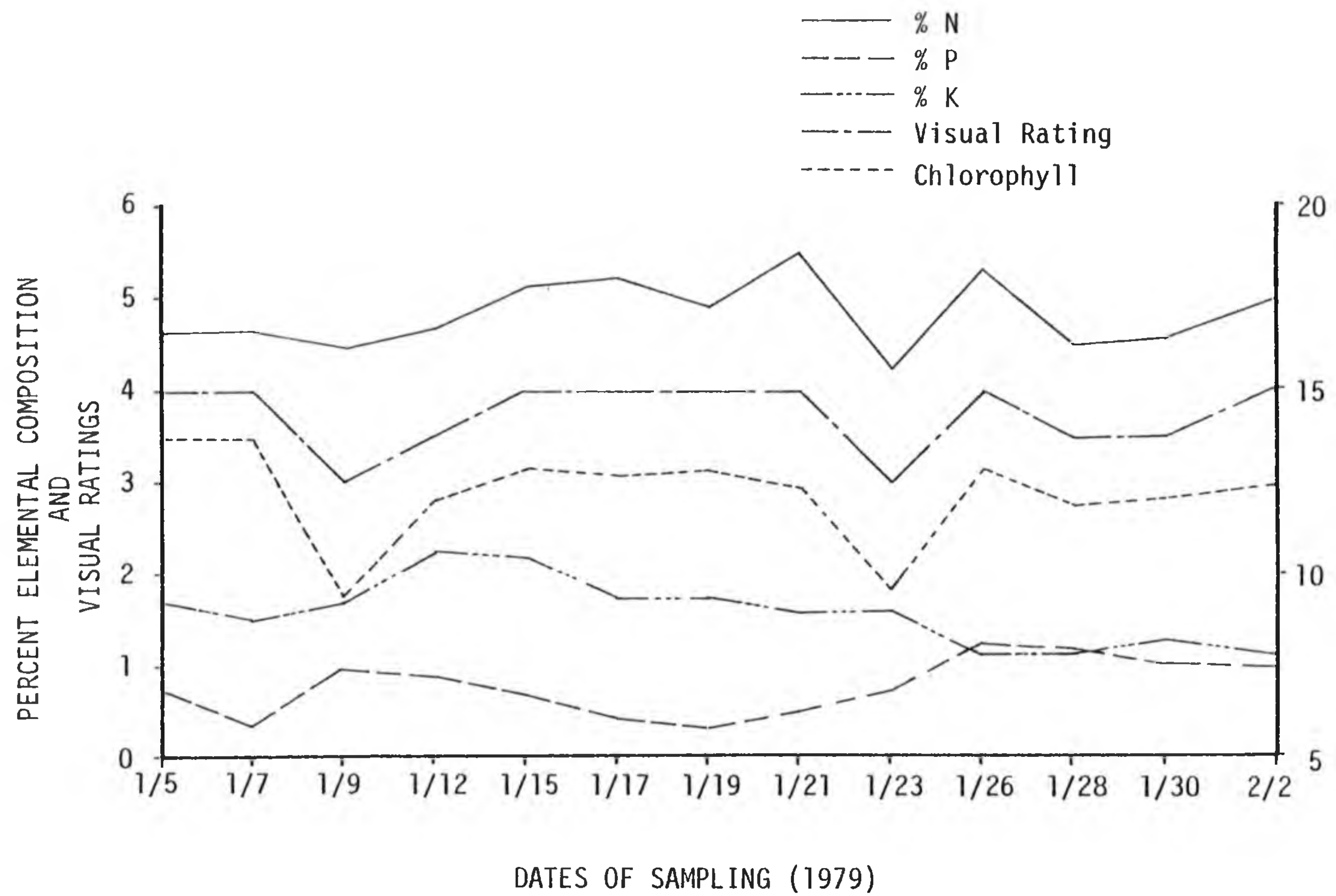

Figure 57. Field Monitoring Program, Green No. 11, Waialae Country Club.

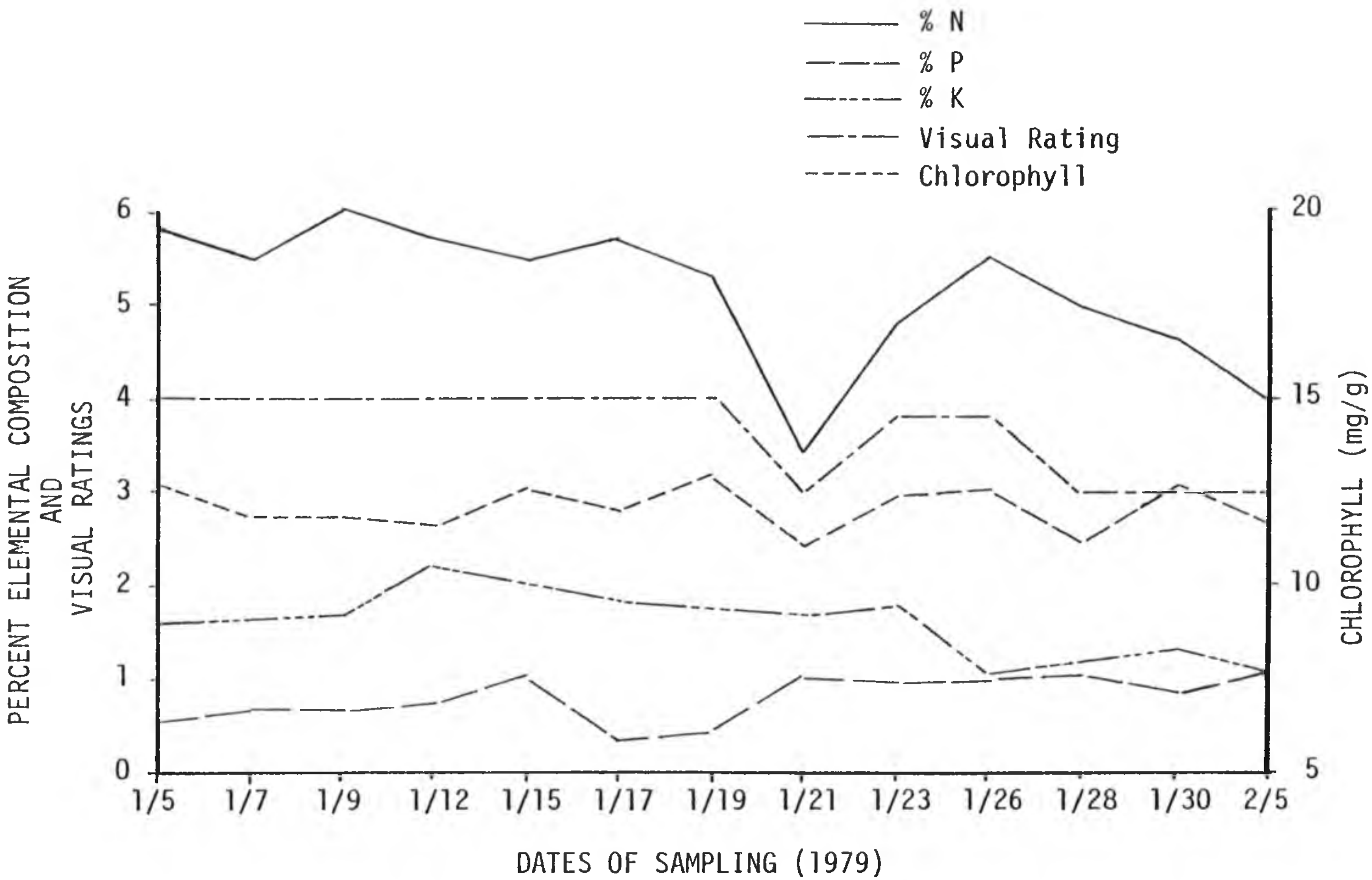

Figure 58. Field Monitoring Program, Green No. 13, Waialae Country Club.

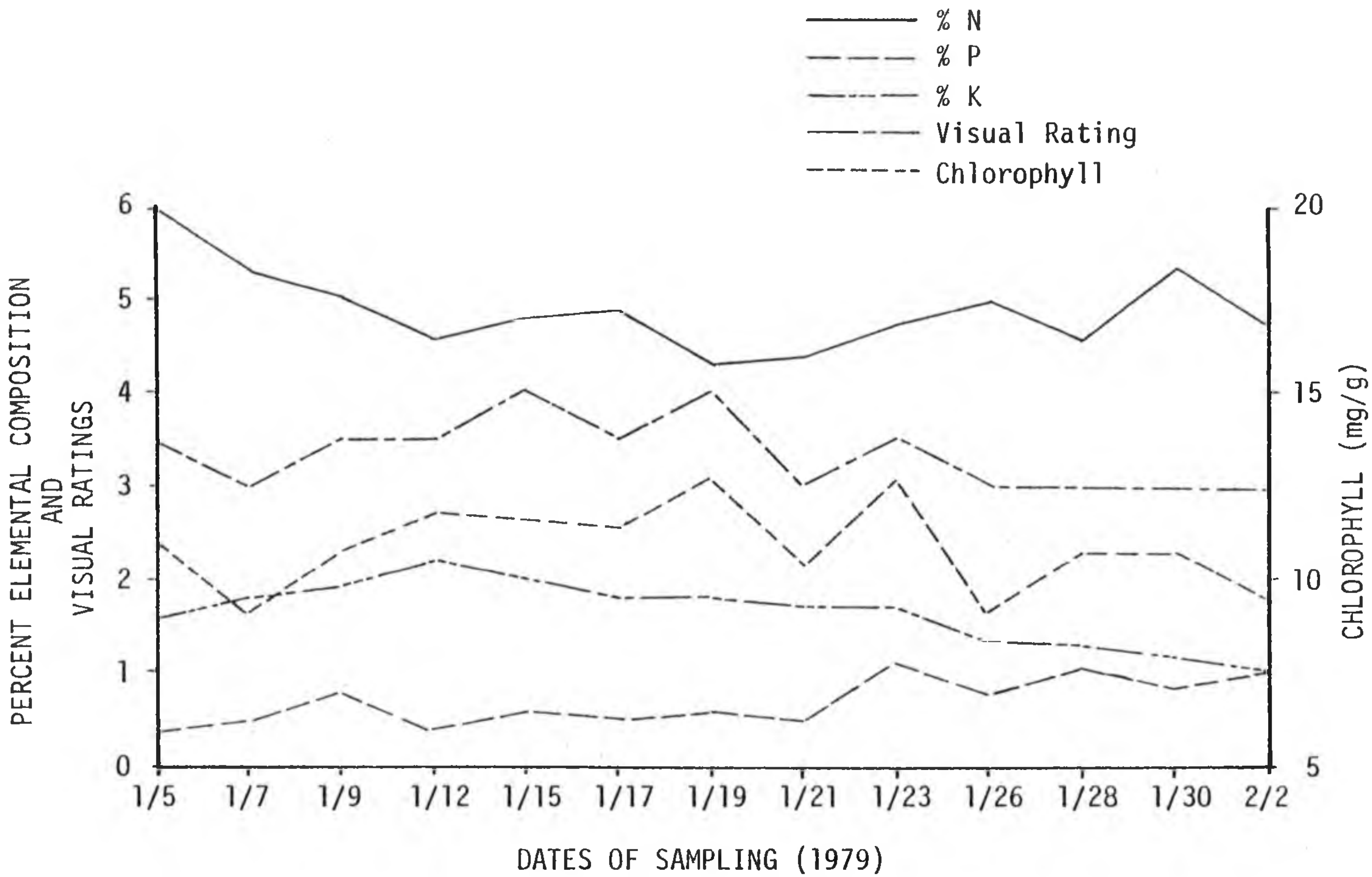

Figure 59. Field Monitoring Program, Green No. 14, Waialae Country Club.

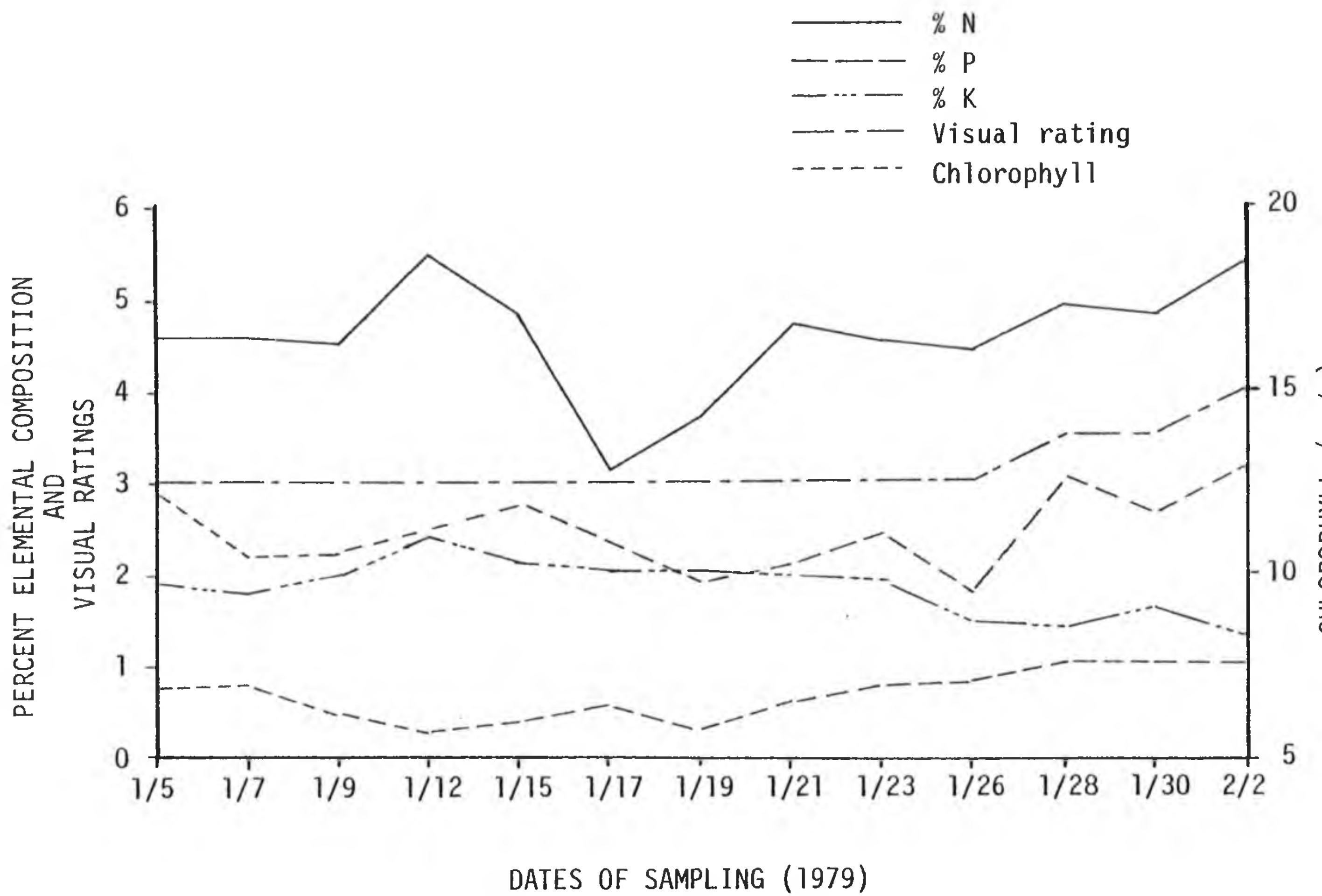

Figure 60. Field Monitoring Program, Green No. 18, Waialae Country Club.

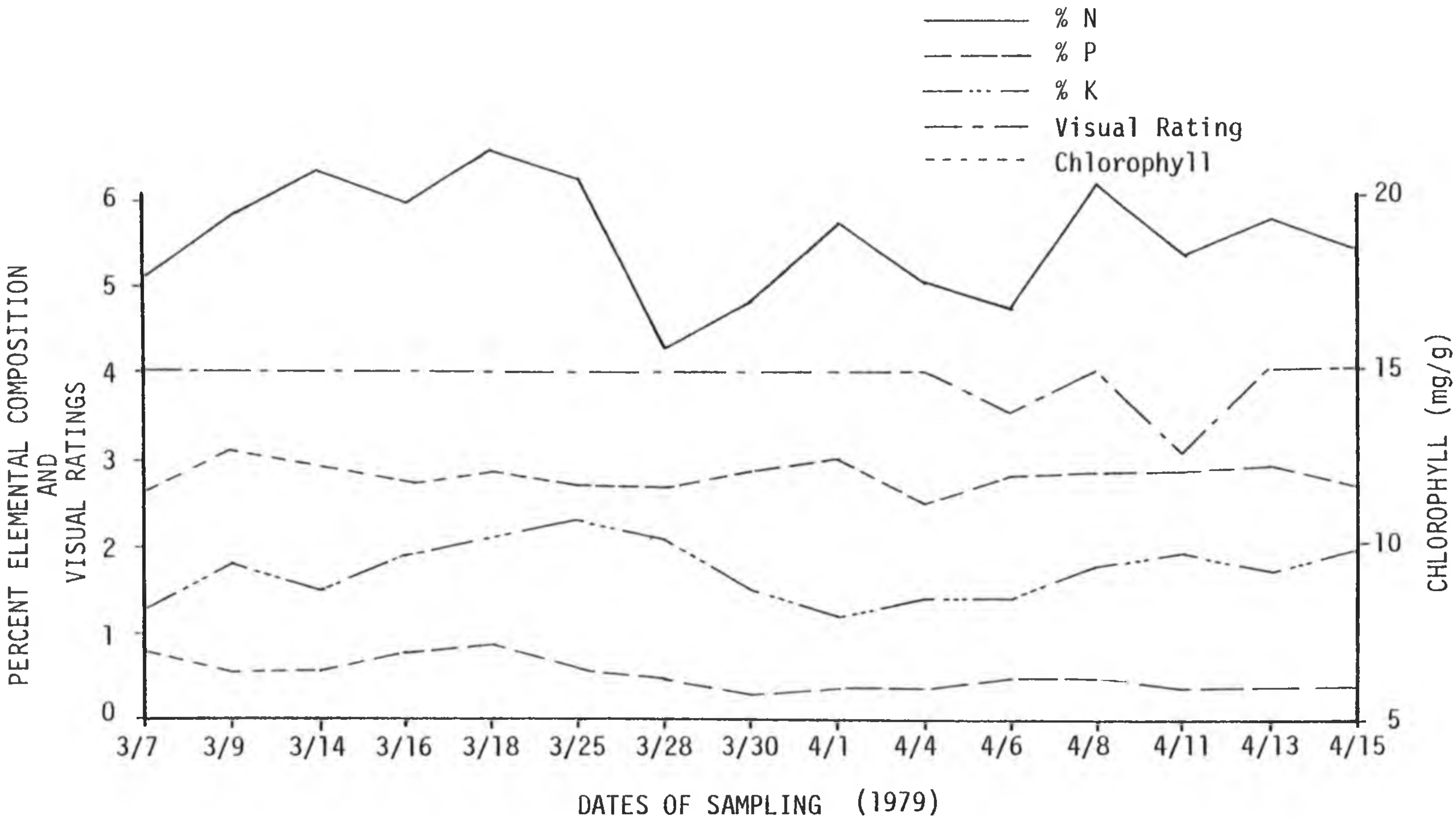

Figure 61. Field Monitoring Program, Green No. 11, Waialae Country Club.

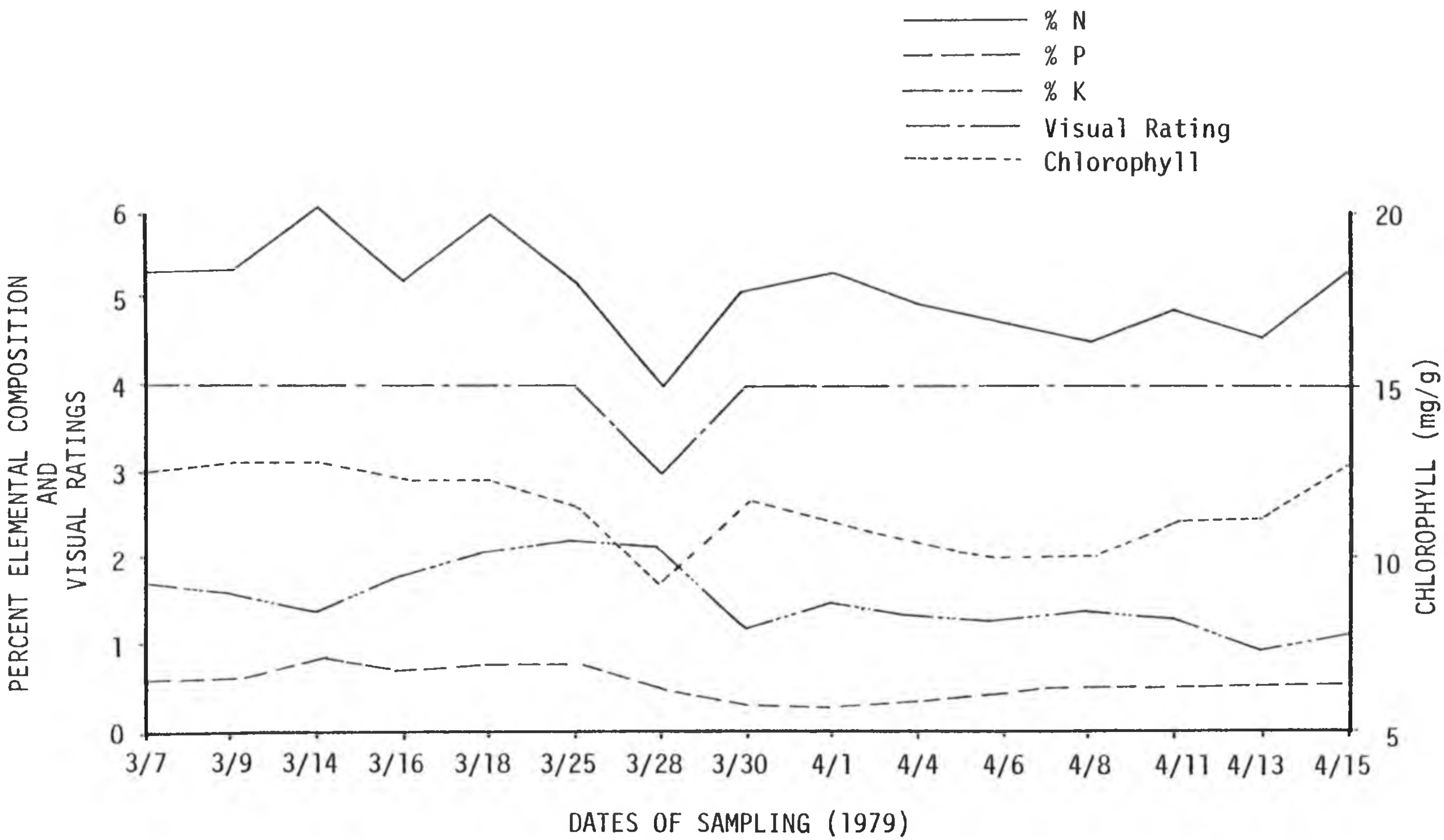

Figure 62. Field Monitoring Program, Green No. 13, Waialae Country Club.

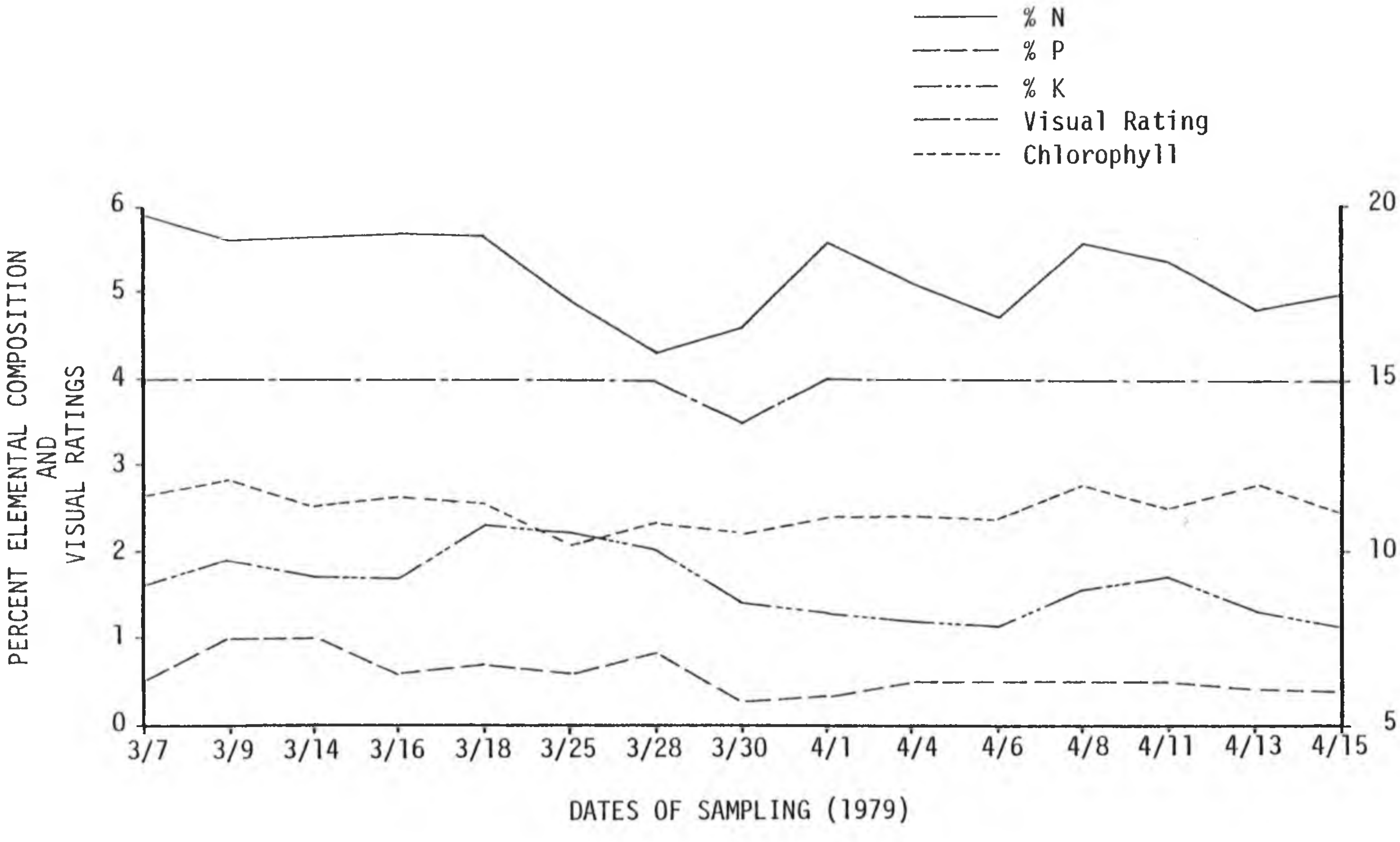

Figure 63. Field Monitoring Program, Green No. 14, Waialae Country Club.

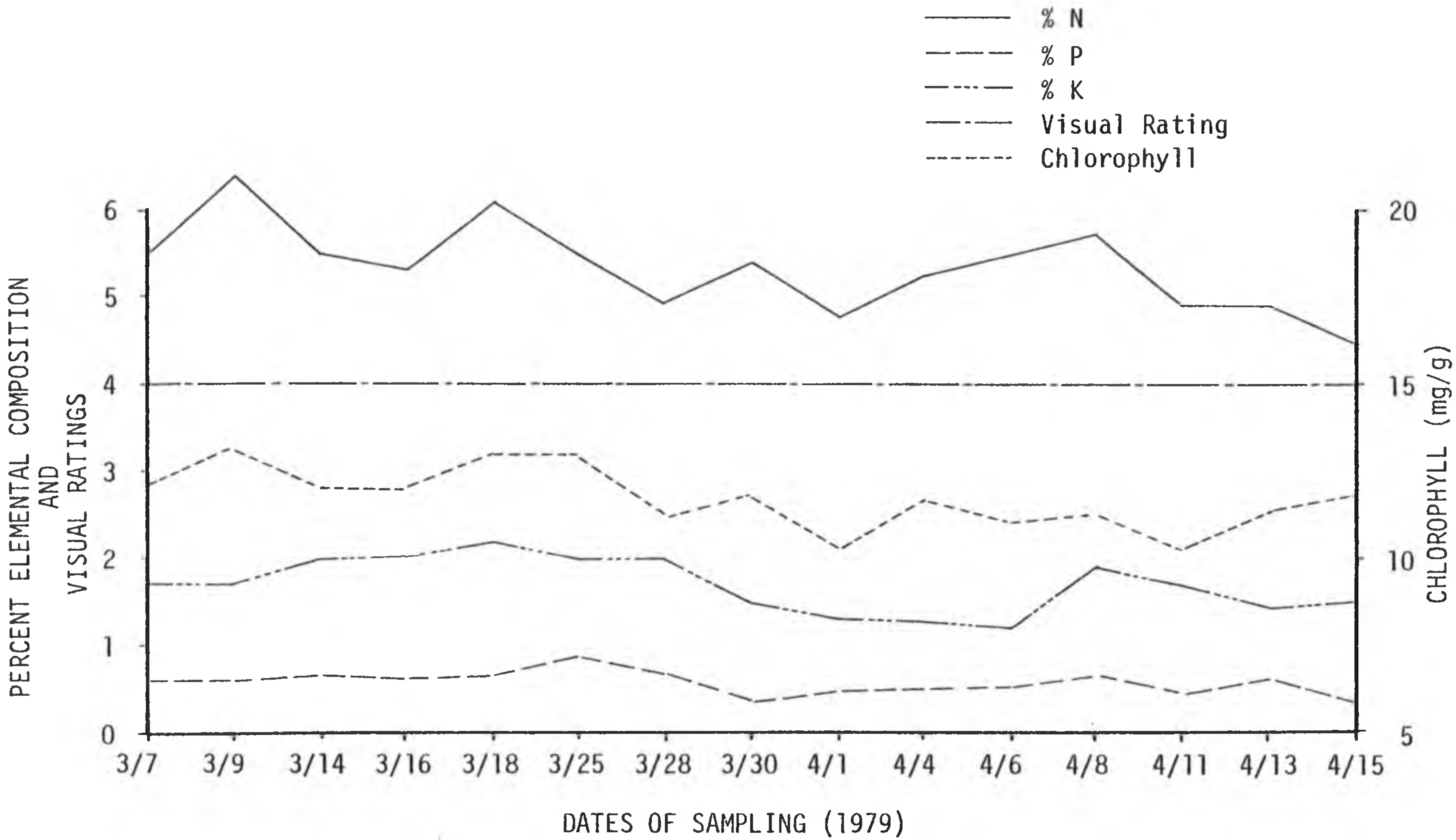

Figure 64. Field Monitoring Program, Green No. 18, Waialae Country Club.

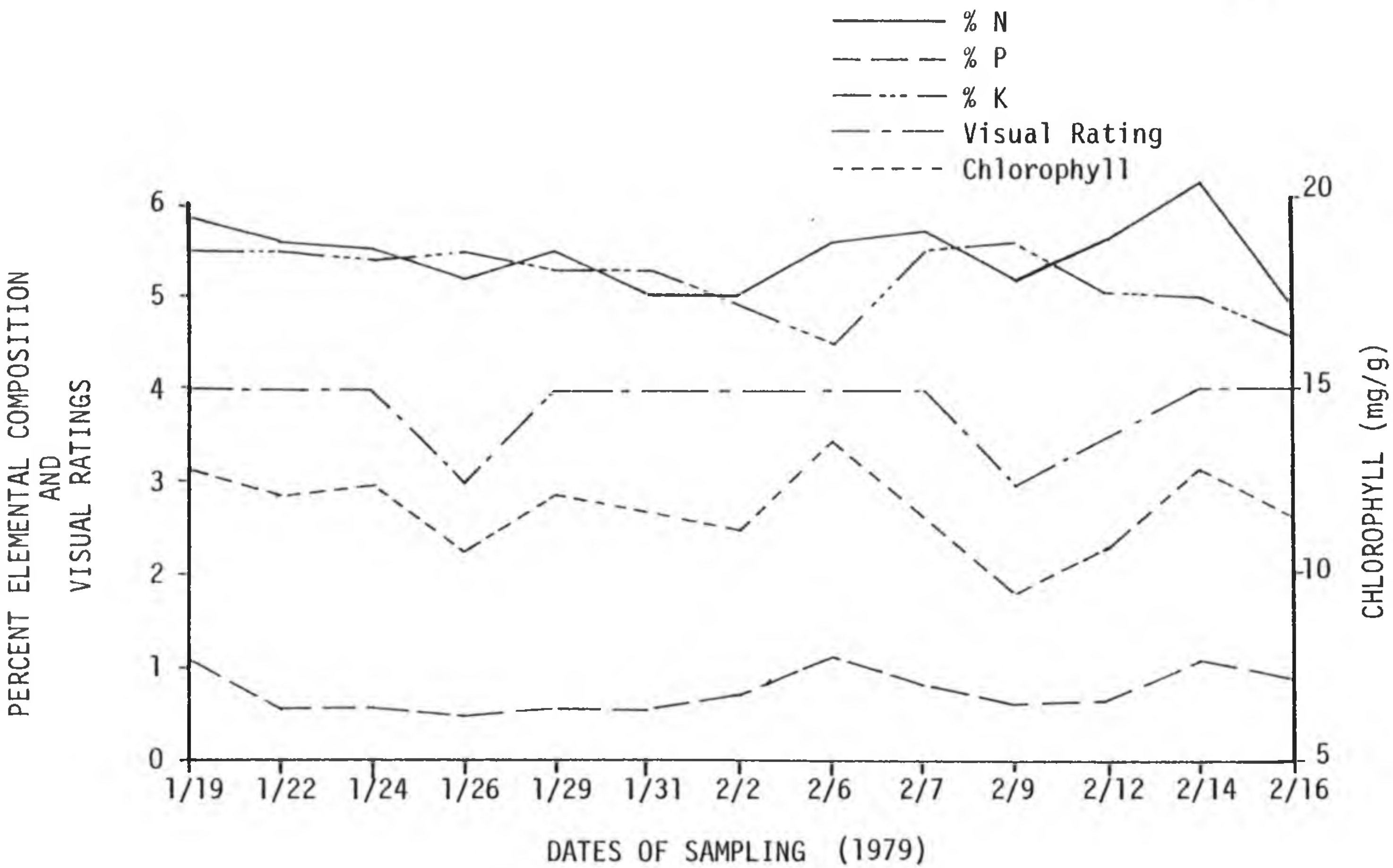

Figure 65. Field Monitoring Program, Green No. 2, Oahu Country Club.

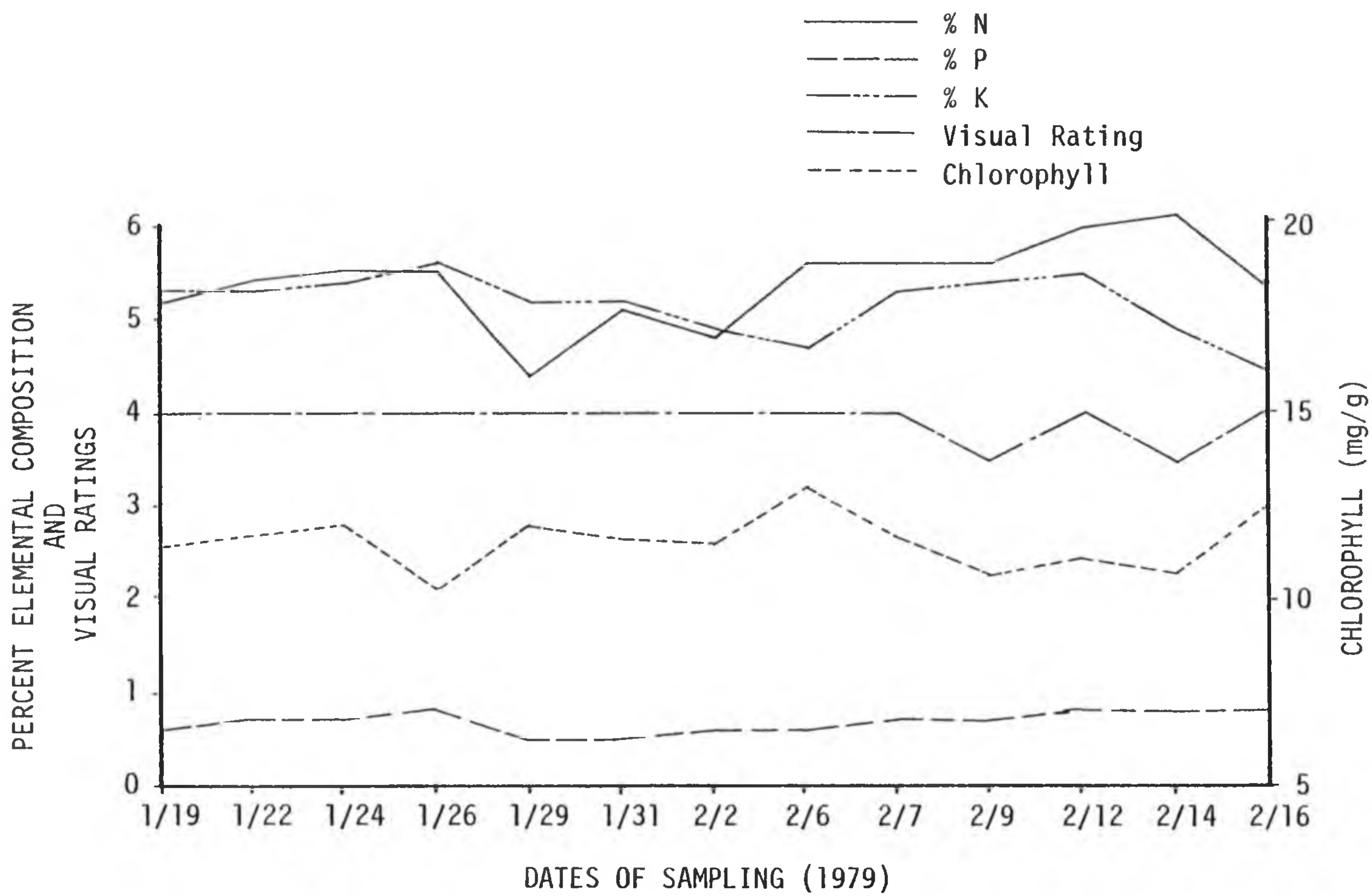

Figure 66. Field Monitoring Program, Green No. 6, Oahu Country Club.

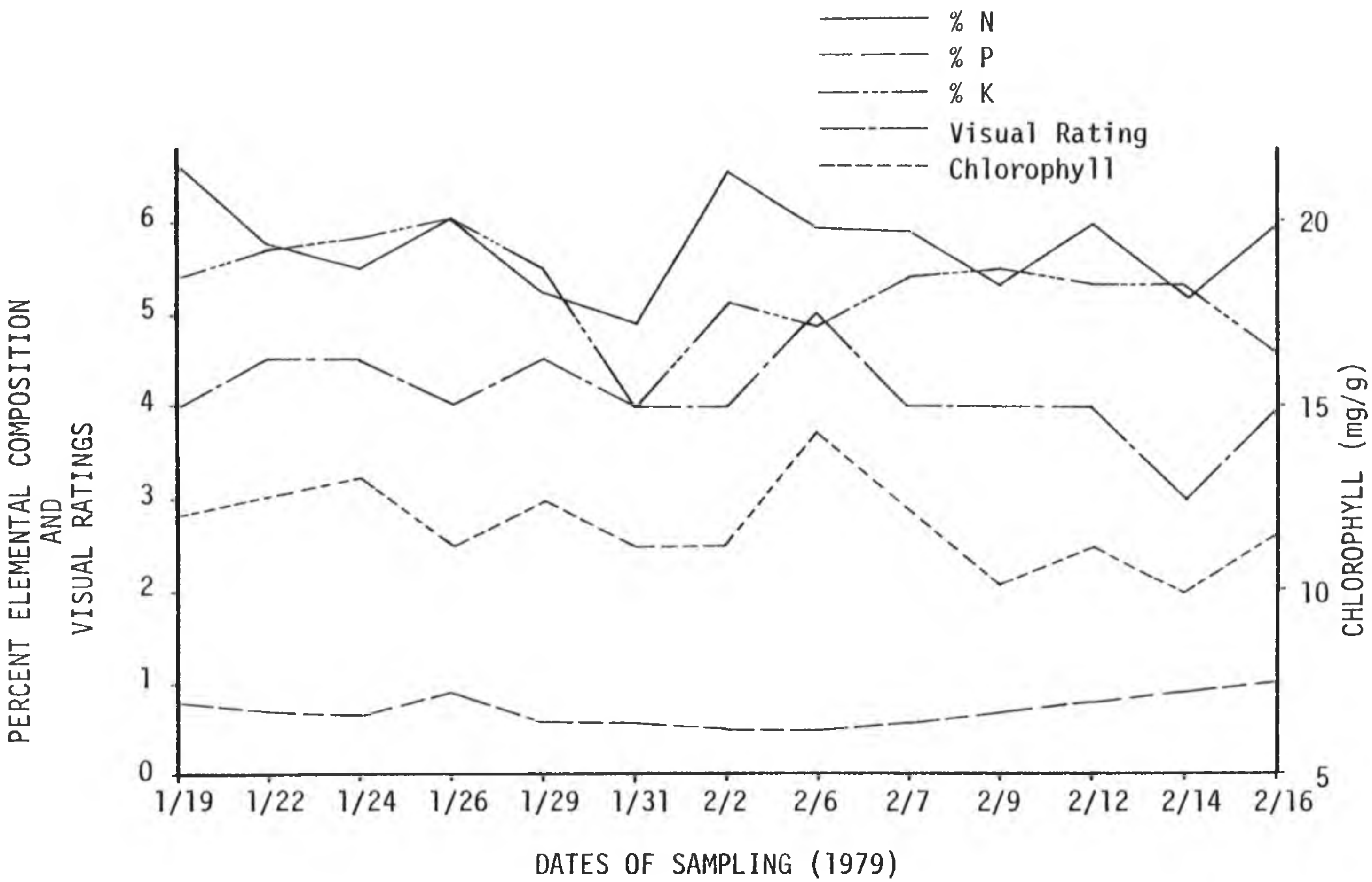

Figure 67. Field Monitoring Program, Green no. 7, Oahu Country Club.

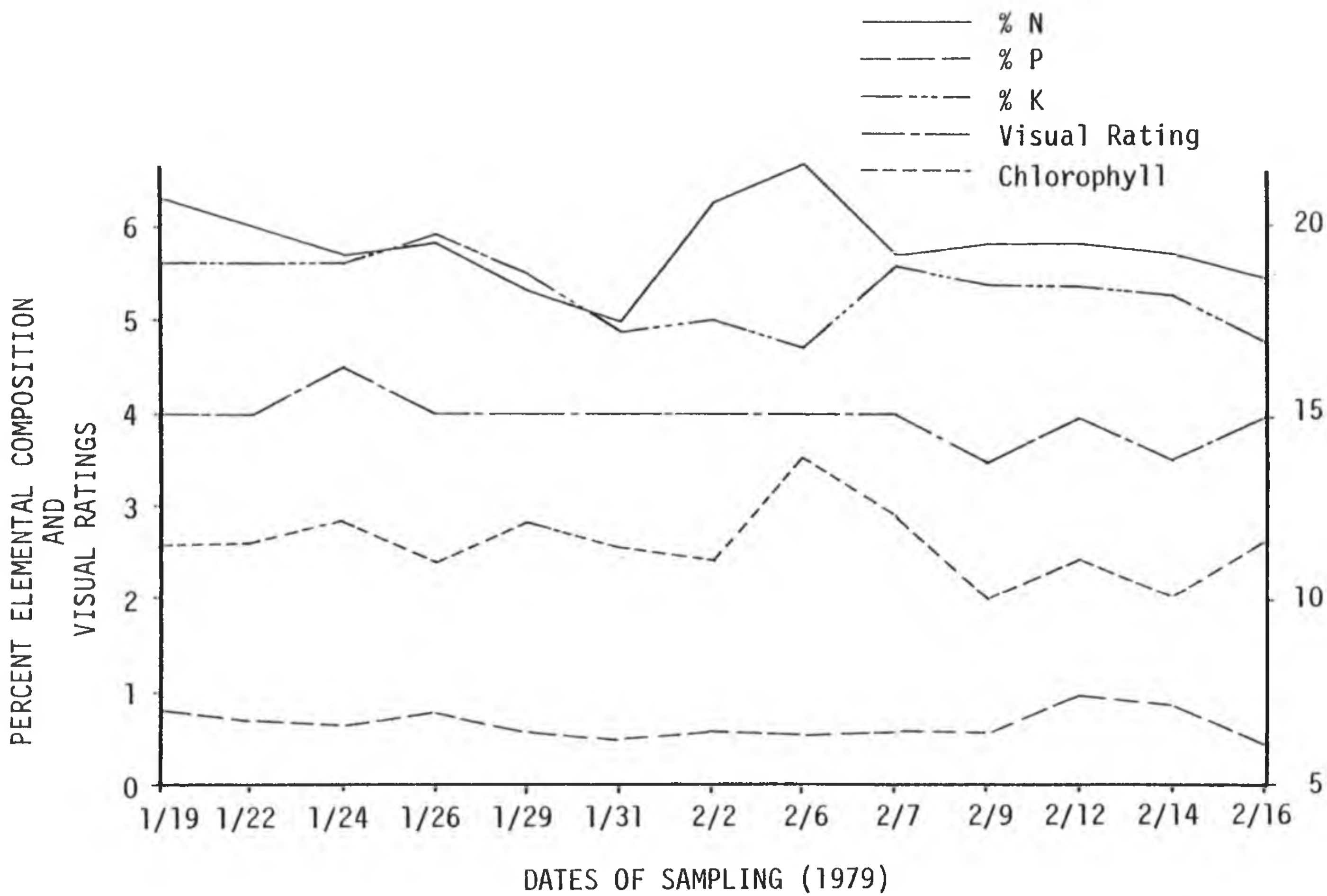

Figure 68. Field Monitoring Program, Green No. 9, Oahu Country Club.

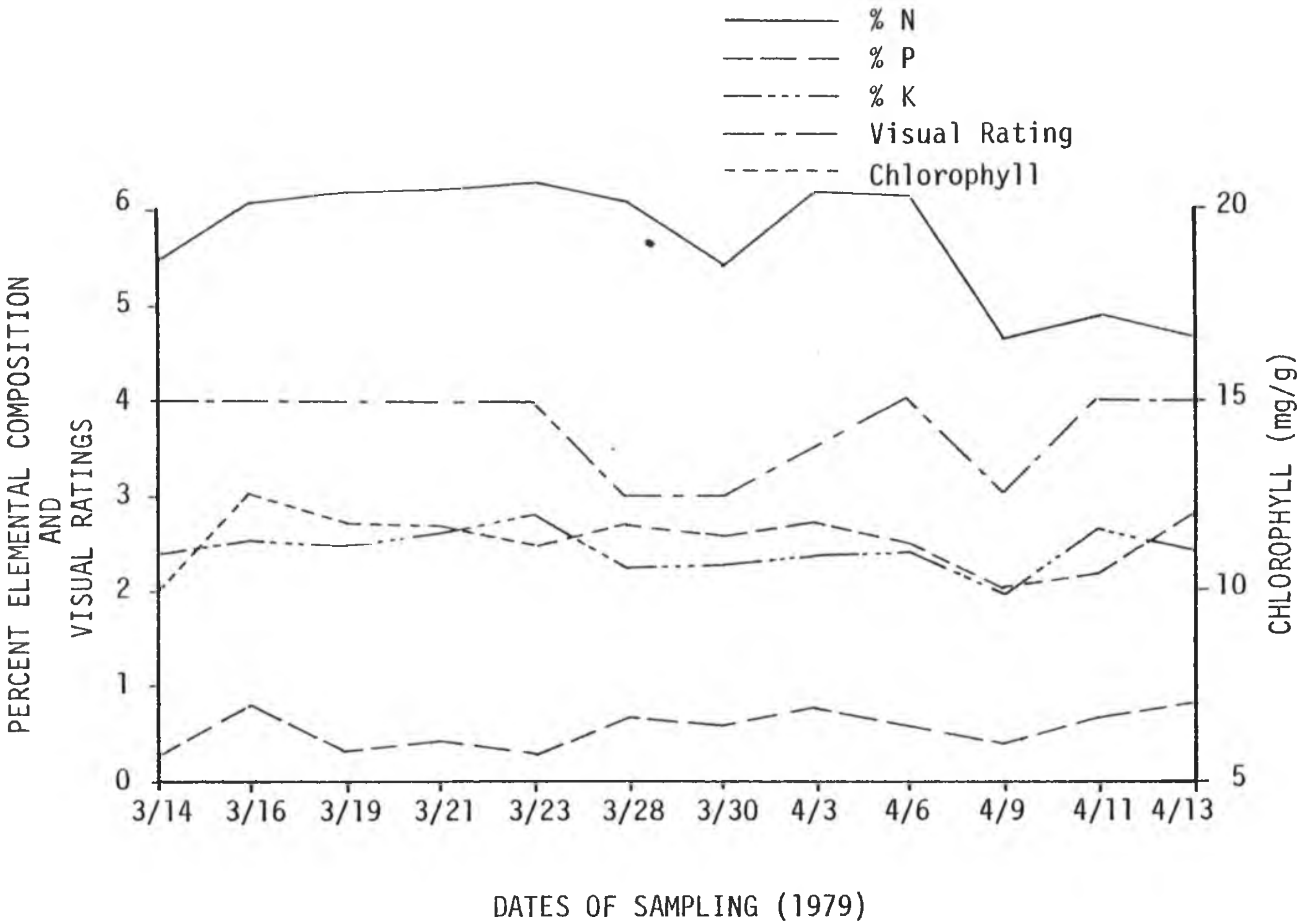

Figure 69. Field Monitoring Program, Green No. 2, Oahu Country Club.

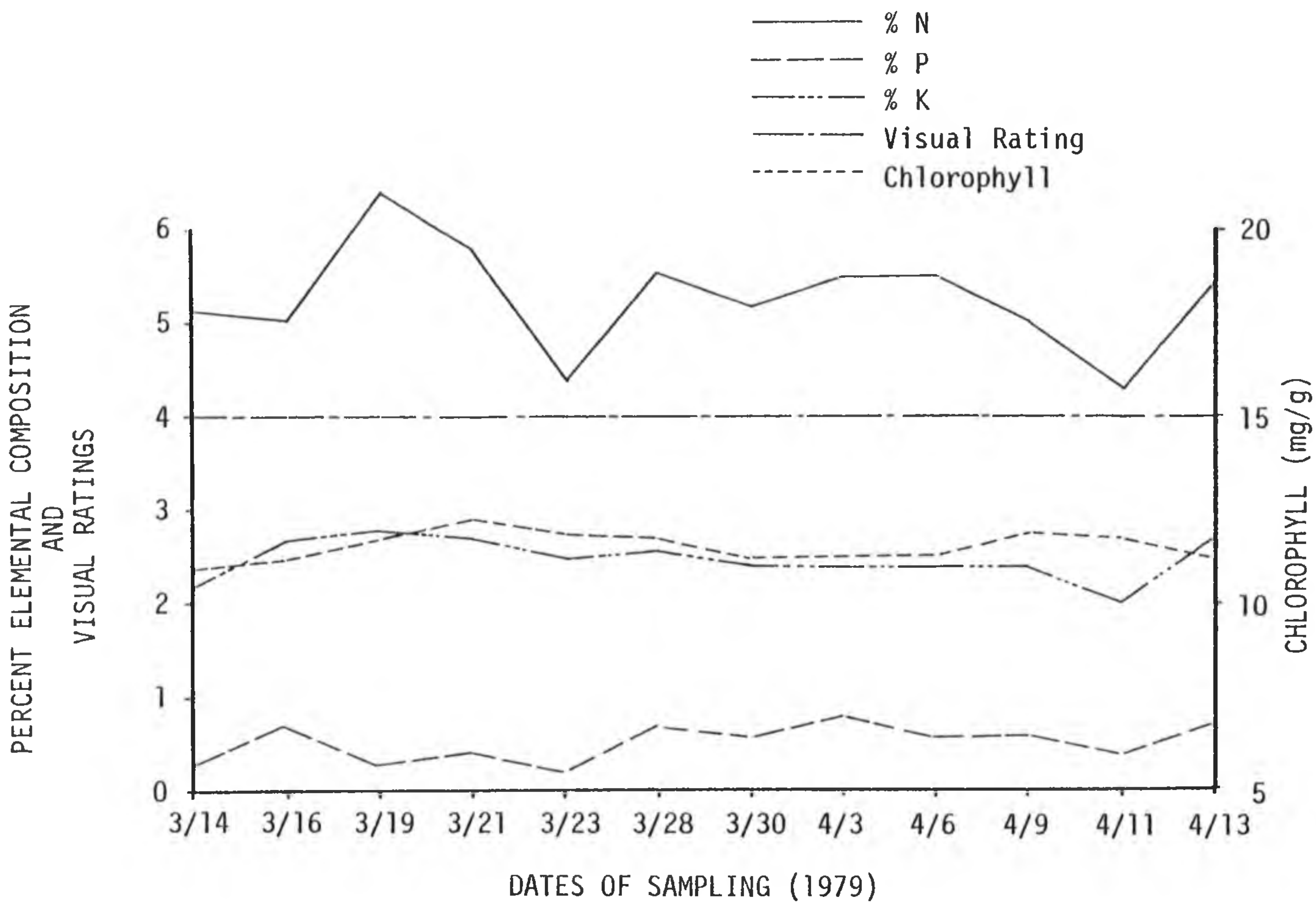

Figure 70. Field Monitoring Program, Green No. 6, Oahu Country Club.

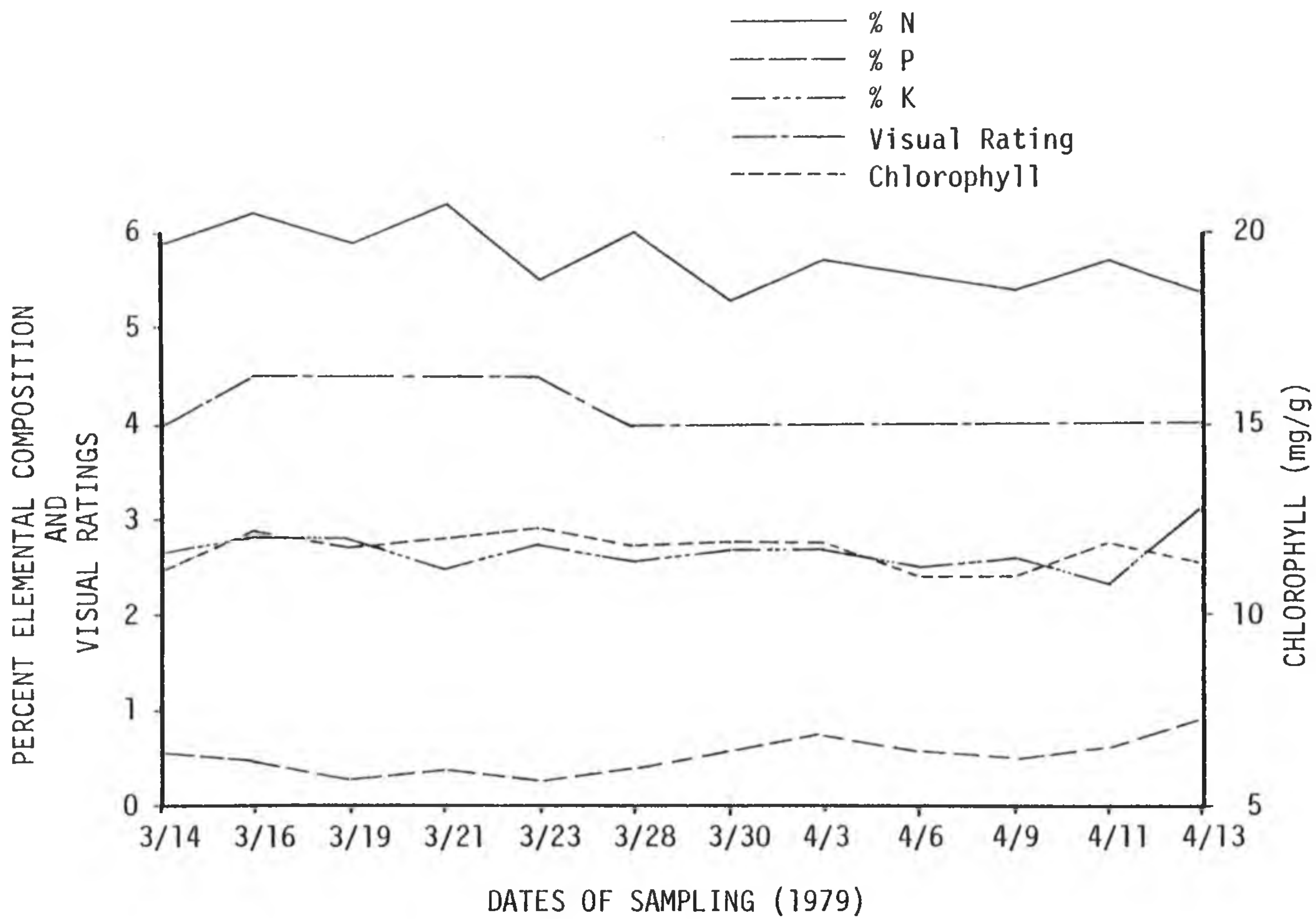

Figure 71. Field Monitoring Program, Green No. 7, Oahu Country Club.

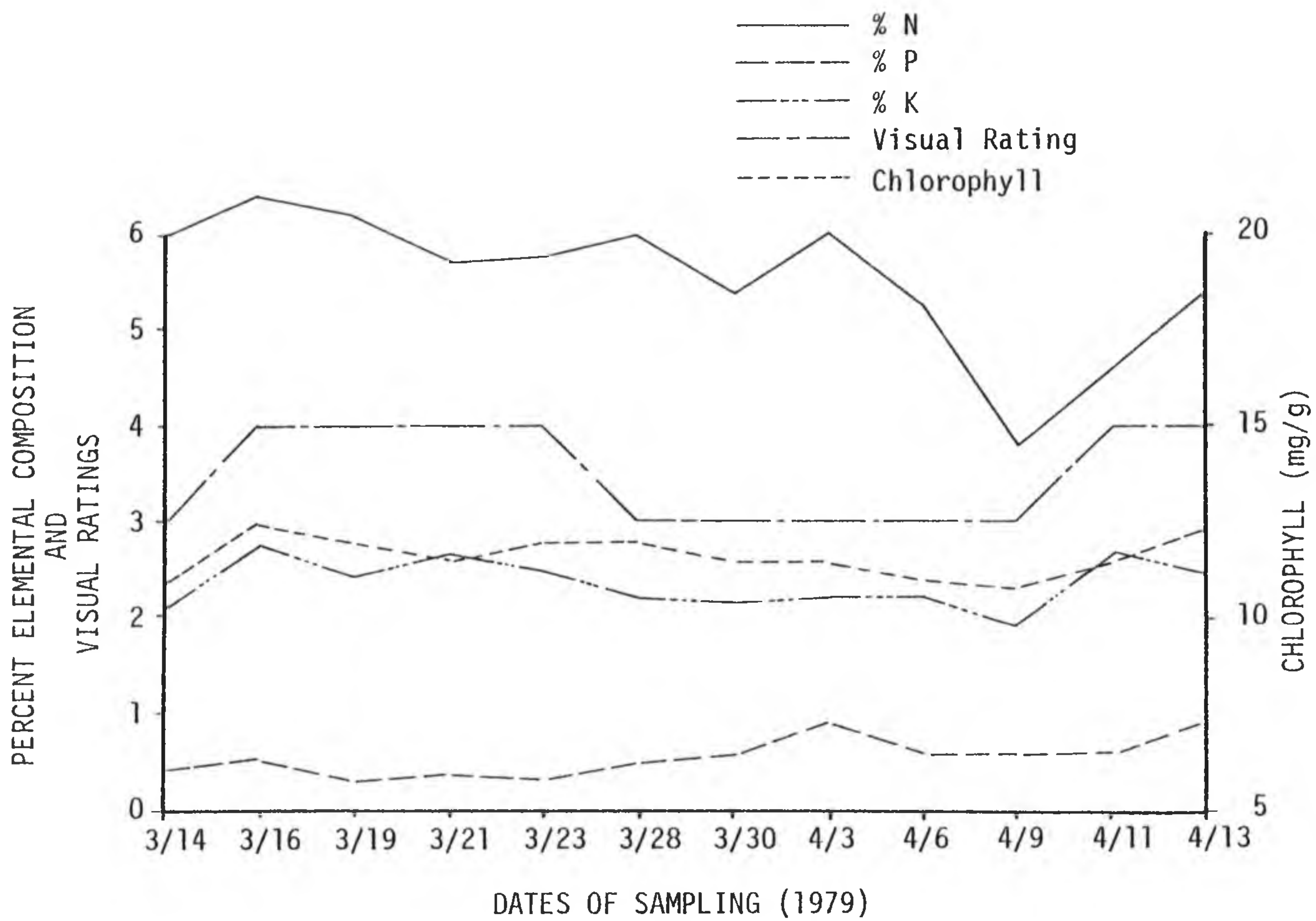

Figure 72. Field Monitoring Program, Green No. 9, Oahu Country Club.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Experiment I. Glasshouse

At the inception of the present experiment, two questions were posed, (1) What responses, relative to the visual quality, and color of turf and the elemental composition of N, P, and K in the turf leaf tissue, will be exhibited with increasing levels of applied N, P, and K to the growing medium? and (2) Are the differences in turf responses significant between increments of applied nutrient, taken separately...? In attempting to answer these questions, varying levels of N, P, and K, taken separately, served as independent variables by which the exhibited responses were measured.

That N ranks first in importance in the determination of Tifdwarf bermudagrass quality was clearly demonstrated by the dramatic effect of increasing N fertility levels on all four primary parameters, VR, DW, CC, and %N. The results firmly established the effectuality of increasing N levels on the visual quality of Tifdwarf bermudagrass. Besides a remarkably high positive correlation coefficient of 0.970, significant mean differences for N level increments were obtained. Moreover, the mean differences were found to be less for higher N levels than for those lower, as reflected by the plateau seen on the response curve (Figure 1). This same trend was observed for all the primary parameters. In general, turf pots treated with low N levels had an unthrifty, spindly appearance, while those treated with high N levels were vigorous and succulent. As will be soon discussed in greater detail, turf quality may have also been greatly influenced by the kind of growth and color intensity manifested. These findings on Tifdwarf bermudagrass corroborated well with those found by researchers working with other turfgrass species, among them, Kikuyu grass (Mantell and Stanhill 1966), bluegrass-red fescue (King and Skogley 1969) and Tifgreen bermudagrass (Menn and McBee 1970). The results for DW closely paralleled those for VR; with r = 0.929, growth as measured by DW was significantly affected by N levels. In view of the high correlation with CC, soon to be discussed, this finding is not surprising. In brief, decreased chlorophyll synthesis results in a slow-down of photosynthesis causing the turf to lack not only essential amino acids but also the machinery for the synthesis of carbohydrates and carbon skeletons necessary for growth. As was expected, growth was retarded and slow at the lower N levels; luxuriant, at the high levels. Growth responses by Tifdwarf bermudagrass to varying N levels then were found to be similar to other grass species, including barley (Arnon 1939), bluegrass-fescue (King and Skogley 1969), and Washington creeping bentgrass (Roberts 1969). Perhaps most evincive of significant effects of N levels on Tifdwarf bermudagrass were those for CC. With an impressive r value of 0.972 for its relationship with N levels, CC or leaf color may be attributed to the role of N as an essential component of the chlorophyll molecule as alluded to earlier. When N supply is low, inhibition of chlorophyll synthesis might be expected; in keeping with this expectation, general blanching or chlorosis was the most dramatic of all the characteristic deficiency symptoms. With ample and very ample N supplies, on the other hand, healthy green color was manifested. Working with Kikuyu grass, Mantell and Stanhill (1960) obtained similar findings. Similarly, %N was found to be correlated at a significant level to N fertility levels. Epstein (1972) suggests that this relationship may be attributed to the ability of N, if readily available, to be absorbed in amounts well in excess of metabolic requirements. This absorption, larger than required for optimal growth, is called "luxury consumption." When exposed to increasing concentrations of N, as happened with increasing applications of N fertilizer to turf pots, the turf absorbed N with increasing avidity. Supplementary mean difference analyses of %P and %K yielded divergent results; that is, trends in the %K mean differences data conformed to those noted for the parameters just discussed, while %K data yielded non-significant differences. Epstein (1972) suggests that this coincidence of %N and %K trends may be due to N and K possessing ion transport systems of the same type. Results for %K were less clear-cut, but a similar trend was at least suggested. In conclusion, then, increased levels of N fertilization yielded Tifdwarf bermudagrass of higher visual quality, heavier growth, greener foliage, and higher elemental composition of N and K. Appreciable differences were obtained for all parameters with the exception of %K with increments of N levels.

Overshadowed by the striking responses to N levels, those for increasing P fertility on all four primary parameters, VR, DW, CC, and %P, were seemingly minimal. Correlation coefficients for VR and %P only were significant, albeit low. As predicted by Duble (1977a), symptoms of P deficiency were difficult to identify by visual inspection of the turf. Contrary to the results obtained by Freeman (1964), spindly and dwarfed growth characteristics of P deficiency were not manifested. The only perceptible deficiency symptom was that of yellowing, and that was slight. Not surprisingly, then, the effects of increasing P levels on CC and DW were non-significant. Parameter mean differences between P increments were, however, found to be significant for the most part. In conclusion, then, while significant effects were not obtained, the importance of P as an essential element cannot be minimized. Incorporated into adenosine triphosphate, ATP, P as phosphate plays a key role in the energetics of metabolism and biosynthesis. P is part and parcel of the universal "energy currency" of all living cells, those of Tifdwarf bermudagrass not excepted. By inducing immediate and severe disruptions of metabolism and development, P deficiency would be scarcely less disasterous than that for N. As reported by Jackson, Walker, and Carter (1959), bermudagrass failures have been reported on old sods depleted of P. The reason for the lack of P effects can only be speculated for the present experiment. Needed in only but the smallest quantities, sufficient P from the Hoagland solution may have perhaps remained in the sand medium to meet turf needs. In analyzing for nutrient effects such as those for P in the present experiment, soil analysis together with leaf analysis would provide a more complete evaluation on the P status of the turf.

Potassium has been aptly given the monker, "the neglected nutrient." As with P, its effects on the visual quality, growth, color and elemental composition of N, P, and K in turf tissue were not as pronounced as those for N. The importance of K, like P, however, cannot be underestimated, as K fertilization is essential for a healthy, vigorous turf (Hampton 1965). Referred to as the "health nutrient" by Hampton, K serves a key role as a catalyst to accelerate plant chemical reactions and as a preventor of disease, particularly Helminthosporium spp. Although a significant correlation coefficient of 0.603 was obtained for VR with K level, the VR means fell within a narrow range. Variations between VR means were small, relative to those for N, but nevertheless significant. Mean differences were found to be greater for lower K levels than for those higher, as reflected by the response curve plateau beyond 50 ppm K. A similar response curve was also plotted for %K and K level. Only those turf pots treated with the lowest levels of K showed any distinct deficiency symptoms; these were, as mentioned earlier in the results section, narrow, pale green leaves, thinning and reduced growth and tip necrosis. The other turf pots were all rated acceptable or better. These VR effects of increasing K levels were in agreement with those reported for other grass species, among them, timothy (Brown and Belyea 1958), zoysia and bermudagrass (Sturkie and Rouse 1967), and Tifgreen bermudagrass (Menn and McBee 1970). DW and CC effects were found to be non-significant; these effects corroborates with Hampton's observation (1965) on the minimal effect on K levels on the growth and color of turf. For DW and CC, K deficiency was not evident and could have been easily overlooked. These results, on the other hand, were incongruent with those obtained for bentgrass by Waddington and others (1972), who found significantly positive relationships between K levels and growth and color, respectively. The clue to the explanation of these non-significant results in the present experiment was to be found in the %K data, as a highly significant correlation was obtained for %K and K level ($r = 0.918$). Even the %K at the lowest K level was relatively high. As was noted for N, K is one of those certain elements that may be absorbed in luxury consumption proportions. It is not unreasonable then to speculate that the turf pots treated with low K levels were able to bide their "K starvation period" quite handily due to its previous luxury consumption of K provided for by the Hoagland's solution. Duble (1977b) stated that where K is available in sufficient amounts, the grass will absorb much more than it requires. That this is true might have been borne out by the obtained data, as seen in the relatively steep slope of the response curve across all the K levels, that is, no plateau is to be found. Supplementary analyses on mean differences yielded significant differences for %N means, but notfor %P. As mentioned earlier in the N discussion, the coincidence of %K and %N uptake may be due to ion transport systems of the same kind for K and N, but not for P. In conclusion, then, increased levels of applied K yielded Tifdwarf bermudagrass of higher visual quality and higher %K content; growth and color, on the other hand, were unaffected. Appreciable differences were obtained for all of the parameters with increasing K levels, with the exception of %P.

Experiment II: Outdoor Environment Studies

There is some difference in opinion expressed in the literature as to whether nutritional data obtained under unnatural conditions as in a greenhouse or glasshouse, as in the present experiment, are valid for use in the field. The primary purpose of Experiment II was to address the following question posed earlier in the introduction: Are the results obtained for treatments grown under artificial, glasshouse conditions generalizable for use in the field?

Experiment I, then, was for all practical purposes reproduced in the field; the major difference was that the turf pots were subjected to a different set of environmental conditions. In agreement with the literature by researchers who found that their green- or glasshouse nutritional data were valid for use in the field, among them Lundegardh (1951) working with pot studies and Bould (1964) with sand cultures, the results of the present field experiment corresponded well with those for the glasshouse, barring a few interesting exceptions to be discussed shortly.

The glasshouse and field data for N were in remarkable accordance with one another, except for DW, where the relationship was linear (Figure 29), which suggests that a maximum amount of N was not available to cause a "leveling off" effect in the curve. For the other parameters measured however, trends obtained were almost identical and the curves were closely aligned one with the other. Without exception, the correlation coefficients for each set of parameters (glasshouse and field) were within $\pm$ 0.11. Consistently, the r values were higher for the glasshouse condition. Given the differences in environmental factors between the conditions, e.g. higher glasshouse temperatures and humidity; shorter light duration and less light intensity for the field experiment, which commenced in late fall, as compared to the glasshouse experiment, which was initiated in early summer; heavier watering for the field due to rainfall, which in turn resulted in increased leaching; and greater susceptibility to disease and insect infestation in the field, the lack of broader differences was unanticipated. The more adverse conditions of the field were somehow compensated for. The reasons for this outcome can at best be speculative. Perhaps, compensation was achieved by increased N fertilization by stolon decay which contributed to organic matter, together with that contributed by the heavy winter rainfall working on the organic medium accumulating in the growing medium, in turn influencing the amount of N available as the result of biological mineralization. Moreover, small quantities may have also been derived from lightning activity during the seemingly all too frequent rainstorms of that winter season (Beard 1973). In conclusion, for N, the glasshouse results were clearly confirmed by the field experiment.

In contrast, the field experiment for P yielded appreciably different data from that obtained in the glasshouse. For all primary parameters, VR, DW, CC, and %P, the ranges of turfgrass responses to P fertility levels were broader for the field condition. This is more than likely due to the longer time period allotted the field experiment, as a result of inclement weather, insect infestation, and fungal outbreaks; apparently, symptoms were able to express themselves more fully given this time extension. For all but DW, parameter values were depressed for the field experiment. These depressions may be attributed to the adverse conditions of the field, as cited in the discussion for N. Perhaps, the most interesting result was that obtained for DW; higher DW values were obtained for the field condition. Perplexing at first, an article by Knoop (1972) served to elucidate this unexpected finding. Again, one can only be speculative, but perhaps due to the increased leaching precipitated by the heavy rainfall, a lesser supply of P than was actually applied was available for uptake. Knoop cites that P fertilization increases the root growth at the expense of top growth, likely a situation truer for the glasshouse condition than for the field due to leaching. As a result, then, the DW for the field reflected its attenuated supply by conceivably less root growth and more top growth than for the glasshouse condition. In conclusion, the generalizability of glasshouse data for use in the field was not conclusively substantiated. Valuable information was nonetheless reaped, as the field experiment directed attention to an unseen limitation of the glasshouse experiment, that is, for P, longer trial periods may be necessary for the manifestation of a braod spectrum of turf responses by which to evaluate P fertility levels. This consideration deserves study and should contribute to increased generalizable glasshouse data for the field.

The field conditions for K yielded data differences which were similar to the results just discussed for P. Again, due perhaps to the adverse conditions of the field, depressed values were reported for all four primary parameters, VR, DW, CC, and %K. Except for %K, higher correlations were obtained forthe field condition, signifying a broader range in symptoms across K levels. It might be surmised that the extended trial period allowed the turf time to more fully express responses to the K treatment as happened with P. Again, an important consideration for future K studies was that trial periods must be longer; otherwise, lower correlationsand truncated curves may again result. In conclusion, although the field and glasshouse conditions for K were not found to correspond as well as for N, general trends were identical and perhaps unwittingly shorter trial periods in the glasshouse contributed most to the discrepancy.

From the information obtained it appears that the nutritional data may on occasion be satisfactory for field use. Confirmed by the field test, the data can be used in the application of N fertilizer with increased confidence. By the proper collection of experimental data for P and K, i.e. longer trial periods, similar correspondence of field and glasshouse may be expected. The present experiment clearly demonstrated the effects of time and adverse conditions on Tifdwarf bermudagrass. There is sufficient opinion that such results are not generalizable (Joham 1951, Clements 1946, among others) that generalizability cannot be taken for granted. More applied experimentation for P and K is in order.

In order to answer questions 3 and 4 posed in the introduction, (3) Do the relationships between the elemental composition of N, P, and K in turf leaf tissue and the aesthetic parameters of visual quality, growth, and color lend themselves to the prediction of the occurrence of nutrient deficiency symptoms? and (4) Can the optimum nutrient range in Tifdwarf bermudagrass leaf tissue be determined? If so, then how?, the correlation coefficients between the qualitatively and quantitatively derived aesthetic value parameters, VR, DW, and CC, and the % nutrient in leaf tissue were determined, as well as the intercorrelations between the primary aesthetic parameter, VR, and the secondary parameters, DW and CC.

For N treatments, the extremely high positive correlation coefficients obtained for VR and DW and for VR and CC indicated that growth and color were significant underlying turf quality determinants. The higher correlation of VR with CC than for DW revealed that turf color played a larger role in determining turf appearance. In view of these intercorrelations, we may conclude that the qualitative measurements of aesthetic value, DW and CC, were consistent with the quantitatively derived measurements, VR. Although subjective and further complicated by the degree of sensitivity of the eye to color and the difficulty of evaluating turf quality irrespective of time, location, or personal preference, VR was found to be highly sensitive in detecting changes in the growth and color of the grass as determined by more time-consuming but objective DW and CC methods. Consistent with the intercorrelation results, highly positive and significant relationships were obtained between %N in turf leaf tissue and VR, DW, and CC. In reference to the graphical representation of these relationships (Figure 7, 8, and 9 for glasshouse; 34, 35, and 36 for field), all six slopes were, not surprisingly, similar to one another. In view of the high correlations obtained as reflected by noticeably steep slopes, these graphs were considered reasonable for use in predicting the occurrence of N deficiency symptoms (Menn and McBee 1970). The high intercorrelations of the aesthetic value parameters would suggest that any of them, VR, DW, and/or CC, could be used in making such predictions. In conclusion and in answer to question 3, locating %N values on the abscissa, followed by tracing corresponding aesthetic parameter values, yields estimations for turf quality, in terms of appearance, growth, and color. In direct response to question 3, then, predictions can be reasonably made on whether Tifdwarf bermudagrass clippings contained sufficient N to eliminate probable N deficiency, as illustrated in Figures 7 and 34, symptoms of N deficiency may be expected to appear for %N concentrations below 4.0.

To adequately answer question 4, some digression is warranted. In contrast to most agronomic and horticultural crops, turfgrass is grown primarily for creating an environment aesthetically and physically applicable for recreation and relaxation. That VR of turf quality was in the present experiments regarded as the primary parameter is thus explained. For clarity in understanding the ensuing discussion in reference to question 4, it might be reemphasized that "adequate" turf quality does not connote "optimum," but rather that quality reflected by turf that appears to be neither deficient, nor forced-grown by excessive fertilization which may induce luxuriant growth at the expense of plant vigor. Thus in answering question 4, it was found that the optimum N nutrient range could be determined by locating the VR range of 3 to 4 on the ordinate, then tracing downward to find the corresponding %N value range on the abscissa. Ratings of above 4 were considered "luxuriant" and appeared overstimulated by too high N fertilizer levels. Ranges for Tifgreen bermudagrass were found in similar fashion by Menn and McBee (1970). This same method of locating the optimum nutrient range was applicable for P and K treatments also. For N, in the present experiments, the optimum N nutrient range was between 4.0 and 5.0%, as indicated in Figures 7 and 34.

For P and K treatments, as was pointed out earlier in the discussion, inconsistent data for glasshouse and field conditions were obtained. Adverse environmental factors no doubt played important roles in producing these discrepant results; the more significant role, however, was believed to have been played by the extended trial period for the field condition. Given this longer period, the desired range of characteristic deficiency symptoms by which to evaluate the P and K treatments were manifested. For this reason, greater attention was focused on interpreting the data obtained under field conditions. Results obtained for P and K could be evaluated in a similar manner as that described for N.

For P treatments, the significant and positive correlation coefficients for VR and DW and for VR and CC indicated that growth and color were important determinants of turf appearance. The higher correlation with CC than for DW revealed that turf color influenced VR to a greater degree than did growth. Again, as for N, it may be concluded that the qualitatively derived measurement (VR) for turf quality compared favorably with those quantitatively derived (DW and CC). Although considerably lower than those obtained for N, the correlation coefficients for %P and VR, DW, and CC were statistically significant. Due to this significance, the obtained graphs were considered reasonable for use in the prediction of the occurrence of P deficiency symptoms. Below 0.23%, symptoms of P deficiency may be expected to appear (Figure 43). Moreover, the significant intercorrelations of VR with DW and CC would suggest that while all three parameters could be used in making predictions, VR and CC graphs with steeper slopes may be more satisfactory in evaluating %P in tissue than the DW graph. In conclusion, using the method explicated earlier, estimations of turf appearance, growth, and color can be made from %P in leaf tissue. In answer to question 3, predictions could be reasonably made on whether Tifdwarf bermudagrass clippings contain sufficient P to eliminate probable P deficiency symptoms. The answer to question 4 was affirmative, with the optimum P nutrient range determined to be 0.23 to 0.4% using the method for N and as indicated in Figure 34.

For K treatments, a significant and positive correlation coefficient was obtained for VR vs. DW, but not for VR vs. CC. Growth, but not color, therefore influenced VR to a significant degree. In contrast to results obtained for N and P on these interrelationshipsbetween parameters, the qualitatively derived measurement (VR) of turf quality did not correspond significantly to the quantitatively derived measurement for CC; however, in keeping to the results reported for N and P, VR compared well with DW. Due to this latter intercorrelation between parameters, the graphs for VR vs. %K and DW vs. %K were found to be similar. Moreover, due to the significance of the correlations, these graphs may be considered reasonable for use in predicting the occurrence of K deficiency symptoms, as indicated by their slopes shown in Figures 52 and 53. In answer to question 3, predictions could be reasonably made on whether Tifdwarf bermudagrass clippings contain sufficient K to eliminate probable K deficiency symptoms. Below 1.5% K, symptoms of K deficiency may be expected to appear. In conclusion, then, estimations of turf appearance and growth, but not color, can be made from %K in leaf tissue. The answer to question 4 was again affirmative, with the optimum K nutrient range determined to be 1.5 to 2.0 %K by the method explicated earlier in the N discussion.

To summarize, the relationships between the elemental composition of N, P, and K in turf leaf tissue and the aesthetic parameters of visual quality, growth, and color, with the exception of %K vs. CC, did lend themselves to the prediction of the occurrence of nutrient deficiency symptoms. The optimum nutrient range in Tifdwarf bermudagrass was determineable for N, P, and K, by the method explicated in detail in the N discussion section. Relative to P and K, most confidence in using the % nutrient graphs as a means of prediction of the occurence of deficiency symptoms as well as optimum nutrient ranges can be placed in those for N, given the extraordinarily high correlations obtained. Additional trials are suggested to verify the validity of the optimum nutrient ranges and % nutrient values below which deficiency symptoms can be expected to occur for P and K. Besides data obtained from the present experiments and that done by Menn and McBee, only a minimum of data exists from which the appearance of turf could be predicted based upon tissue analysis. Confirmatory studies and further experiments on N, P, and K, as well as other essential nutrients, can only serve to uplift the present status of research in this important aspect of turfgrass nutrition.

To answer the question, (2) Are the differences in turf responses significant between increments of applied nutrients, taken in combination?, varying levels of P and K with N held constant were applied to the turf pots. Although the P X K interactions were significant for VR, these interactions occurred within a narrow range of 4.5 to 5.0. For all treatments, the turf pots manifested luxuriant growth. In general, slightly darker green and dense turf were characteristic of the treatment combinations of low P and low K, while the treatment combinations of low P with medium and high K produced slightly lighter colored and less dense turf. It must be emphasized that, however, these differences were minimal with this VR range. The significant effects may be attributed to experimental error, as there may have been inconsistent assignment of VR.

Significantly affected by the interaction effect between P and K, the %N values were all in the optimum range as found earlier in Experments I and II. The range of %N content ranged from 4.51 to 4.84, indicating that the largest difference was only 0.33%. Similar to VR, the treatment combination of low P with low K resulted in the highest %N content. In combination with increments of applied K, this low P level reduced %N content. This result may have been due to ion antagonism.

Despite the non-significance of the interaction effects on %P and %K, the values obtained for these % nutrient values were at or above optimum. That is, %P values were above optimum levels (> 0.4%), while the %K values were at or above optimum (> 2%).

The results of the present combination experiment substantiate those of previous research, which found that the effects of %P and %K concentrations in the tissue at or above the optimum concentrations had non-significant effects on VR. For the most part, then, the constant level of N supplied in adequate amounts contributed to the high VR ratings obtained.

In conclusion, the answer to question 2 was not in the affirmative. Further experimentation was indicated in order to obtain more clear-cut results; wider ranges of nutrient levels in combinations with N levels also varied was suggested in view of the results obtained in the present experiment.

To answer the last of the six questions posed in the introduction,

(6) How may the person in the field benefit from the obtained experimental findings?, field monitoring studies were conducted at the Waialae Country Club and the Oahu Country Club in an attempt to answer this question by direct application of the methods used in Experiments I and II and the findings on the optimum nutrient ranges. This attempt to answer this question by illustration proved fruitful. Adjusting the ongoing fertilization programs to better conform with the obtained findings of the present experiments resulted in general, in a reduction of applied fertilizer as well as all of its concomitant costs, e.g. labor, equipment, and material expenses, at no expense to turf quality.

Various aspects of the present experiment were more clearly elucidated and substantiated by these field monitoring studies. Most importantly, the distinct advantages of incorporating leaf analysis to turfgrass management were made salient, as well as the possible drawbacks. By far, the advantages far out-weighed the drawbacks. The most apparent drawback connected with leaf analysis isthe variability that results due to environmental factors, light duration and rainfall, in particular. This was illustrated by the fluctuations in % nutrient, especially for N. Variable results due to environmental factors were seen also between Experiment I in the glasshouse and Experiment II in the field. Yet in spite of the inevitably large experimental errors in the field as compared to the glasshouse, the variations were reasonably limited and in the final analysis the agreement in actual results and trends was surprisingly good. The second drawback is that leaf analysis was found to be unsuitable for the layperson or the unsophisticated turf person, as considerable expertise is needed to interpret leaf analysis data or to use the information to best advantage. The technique is limited to the professional turf person with the wherewithal and experience to make good judgements as to how to use the information most efficiently and effectively.

The advantages of leaf tissue analysis were clearly demonstrated by the field monitoring studies; they were as follows:

1. The turfgrass leaves indicate more precisely the availability of nutrients in the soil, than say VR, CC, or DW. Subject to heavy fertilization, the turf clearly reflected this in their % nutrient content. For both locations, N fertilization in particular was applied in large quantities and the %N in the leaf tissue was found to be in luxury consumption quantities. This observation is in keeping with the finding in Experiments I and II that the concentration of nutrients rises in proportion to the concentration in the growing medium and substantiates statements to this effect by Lundegardh (1943) and Duble (1977a).
2. Leaf analysis not only gives an instantaneous picture of the nutrients available in the soil, but also sums up the extraction of nutrients over a period of time. Figures 57 to 72 illustrates this advantage over a period of several weeks. Normal fluctuations could also be easily observed over time. Leaf analysis provided the information with which a good fertilization program could be designed to minimize the effects ofsuch fluctuations while providing optimum turf quality.
3. Leaf analysis information can be of great value in helping the turf person to economize on N, P, and K fertilizers by avoiding wasteful

use. Excessive fertilization may be as harmful as it can be beneficial to the growth of Tifdwarf bermudagrass. In fact, it is well known that it is easily possible to weaken or even kill the turf by overstimulation, which may induce disease infestation susceptibility of succulent turf to pathogens or fertilizer burn due to excessive salt accumulation. Moreover, overfertilization can increase vulnerability against stress. This last point is particularly cogent to the putting greens observed, as a good playing surface must be maintained. Tifdwarf bermudagrass grown on these greens must have excellent recuperative potential due to intense human traffic, divot damage, and wear from shoe spikes and ball marks.

Besides the economic and aesthetic considerations, the potential for environmental pollution is greater with excessive fertilization. N fertilizer, in particular, has gained notoriety as a source of ground water pollution because of the mobility of soluble nitrate-N and because of the large amounts of N fertilizer used (Smika, Heerman, Duke, and Bathchelder 1977). Prudent and efficient N fertilization must also be a goal of turf persons, and proper fertilization with the use of leaf tissue analysis can play a significant role in minimizing this environmental problem.

In terms of plant nutrition, the danger of overfertilization was clearly apparent with K. A long term fertilization program of K may have ultimately proved detrimental, as high %K content suppresses calcium absorption even if this nutrient is available in normal amounts (Lundegardh 1943). If the ion antagonism resulted in lowered calcium content, growth would have inevitably been retarded.

4. Although the search for "best" or "balanced" elixirs of plants is a time-honored pursuit (Shive 1915 and Shive and Martin 1918), an exact recipe for turf fertilization cannot be provided nor is desirable. Recommendations made for the field monitoring studies to correct for deficient or excessive % nutrient content in Tifdwarf bermudagrass leaves did not conform to any "established" N-P-K ratio. The recommendations suggested on a fertilizer bag then should be used by the turf person only as a base from which to formulate his own specific fertilization program based on the deficiency or excess information obtained by leaf analysis.
5. Leaf analysis provides the quantitative buttress long-needed by visual rating techniques. Turfgrass research has long suffered from the lack of suitable quantitative measurements which could also be qualitatively interpreted (Madison and Andersen 1973). This lack was particularly cogent for turfgrasses as turf is judged ultimately for its aesthetic quality. The use of VR alone has been criticized on the grounds that it is highly subjective (Mantell and Stanhill 1966) and based on arbitrary discrete ratings (Madison and Andersen 1963). The combination of leaf tissue analysis and VR improves on the use of VR alone in three ways: (1) leaf analysis provides a continuous spectrum of values rather than arbitrary groupings, (2) correlated with VR, leaf analysis data can give qualitative information about the degree of aesthetic quality, and (3) the combination of VR and tissue nutrient content can give qualititative and quantitative

information that is less restricted in terms of analyst, season, and location as compared to VR alone

Leaf analysis also improves on growth and color data, as these are aesthetic qualities that in most cases can be reduced with nutrient deficiency, but may be caused by many other factors, e.g. drought, shade, and disease, besides nutrient disorders.

In conclusion, leaf analysis can help to confirm deficiencies or excesses indicated by other parameters. As an example, in the field of monitoring studies, regular observation of the greens may be a good means of avoiding deficiencies since turf appearance responds rapidly to N levels as found in Experiments I and II. A better means might be obtained by VR coupled with leaf analysis as deficiency can be confirmed and overfertilization avoided.

6. Probably the most salient advantage is that leaf analysis indicate approaching difficulties before symptoms of injury appear. This was clearly demonstrated in the field monitoring studies which employed the optimum nutrient levels obtained with leaf analysis to correct nutrient level excesses and deficiencies. Moreover, leaf analysis can be regarded as a means to practice preventive plant nutrition besides its corrective function.

In view of all of these advantages cited, leaf tissue analysis can serve as an invaluable tool by which fertilization programs can be designed and applied with increased confidence. Without question, considerable new information was obtained with leaf tissue analysis for an important warm season turfgrass, Tifdwarf bermudagrass. To the pool of knowledge on this turfgrass was added informationon: (1) Responses, relative to visual quality, growth, and color, and the elemental composition of N, P, and K in the turf leaf tissue, exhibited with increasing levels of applied N, P, and K to the growing medium; (2) the significance or lack of significance of differences in turf responses between increments of applied nutrients, taken separately and in combination; (3) the prediction of the occurrence of nutrient deficiency symptoms based on the relationships between the elemental composition of N, P, and K in turf leaf tissue and the aesthetic parameters of visual quality, growth, and color; (4) the determination of the optimum nutrient ranges for Tifdwarf bermudagrass; (5) the generalizability of data obtained for glasshouse treatments to the field; and (6) how the person in the field can benefit from the obtained experimental findings. As important as these knowledges gained were, equally so, perhaps, was the greater appreciation of a description by Lundegardh (1943) who is regarded as the father of leaf analysis, which reads, "functioning assimilating leaves as the central "laboratories of nutrition."

APPENDIX

Appendix Table 22

Anova for Visual Ratings As Affected by N Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	206.64		
Main Plots				
Dates	3	0.08	0.03	0.50
Replications	2	0.30	0.15	2.50
Error A	6	0.37	0.06	
Sub-Plots				
N(VR)	8	200.41	25.05	357.86**
N(VR) x Dates	24	1.32	0.06	0.86
Error B	64	4.16	0.07	

Appendix Table 23

Anova for Dry Weight Yields As Affected by N Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	77.02		
Main Plot				
Dates	3	1.55	0.52	13.00*
Replications	2	0.34	0.17	4.25
Error A	6	0.21	0.04	
Sub-Plots				
N(DW)	8	69.64	8.71	217.75**
N(DW) x Dates	24	2.41	0.10	2.50
Error B	64	2.87	0.04	

Appendix Table 24

Anova for Chlorophyll Content As Affected by N Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	2464.92		
Main Plots				
Dates	3	22.26	7.42	6.68*
Replications	2	29.10	14.55	13.11*
Error A	6	6.65	1.11	
Sub-Plot				
N(CC)	8	2341.33	292.67	365.84**
N(CC) x Dates	24	14.49	0.60	0.75
Error B	64	51.09	0.80	

Appendix Table 25

Anova for %N As Affected by N Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	152.08		
Main Plots				
Dates	3	1.40	0.47	4.27
Replications	2	0.99	0.50	4.55
Error A	6	0.67	0.11	
Sub-Plots				
%N	8	143.13	17.89	255.57**
%N x Dates	24	1.54	0.06	0.86
Error B	64	4.35	0.07	

Appendix Table 26

Anova for %P As Affected by N Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	6.2224		
Main Plots				
Dates	3	3.8509	1.2837	19.362
Replications	2	0.074	0.037	0.5581
Error A	6	0.3978	0.0663	
Sub-Plots				
%P	8	0.1628	0.0204	1.2071
%P x Dates	24	0.6529	0.0272	1.6095
Error B	64	1.0840	0.0169	

Appendix Table 27

Anova for %K As Affected by N Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	29.15		
Main Plots				
Dates	3	1.96	0.65	2.60
Replications	2	1.05	0.53	2.12
Error A	6	1.52	0.25	
Sub-Plots				
%K	8	22.60	2.83	141.50**
%K x Dates	24	0.68	0.03	1.50
Error B	64	1.34	0.02	

Appendix Table 28

Anova for Visual Ratings As Affected by P Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	26.14		
Main Plots				
Dates	3	1.99	0.66	3.67*
Replications	2	2.37	1.19	6.61*
Error A	6	1.06	0.18	
Sub-Plots				
P(VR)	8	15.41	1.93	32.17**
P(VR) x Dates	24	1.41	0.06	1.00
Error B	64	3.90	0.06	

Appendix Table 29

Anova for Dry Weight Yields As Affected by P Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	7.73		
Main Plots				
Dates	3	2.02	0.67	33.50
Replications	2	0.83	0.42	21.00
Error A	6	0.09	0.02	
Sub-Plots				
P(DW)	8	2.94	0.37	18.50**
P(DW) x Dates	24	0.34	0.01	0.50
Error B	64	1.51	0.02	

Appendix Table 30

Anova for Chlorophyll Content As Affected by P Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	177.48		
Main Plots				
Dates	3	43.31	14.44	11.84
Replications	2	2.98	1.49	1.22
Error A	6	7.31	1.22	
Sub-Plots				
P(CC)	8	76.57	9.57	18.76
P(CC) x Dates	24	14.97	0.62	1.22
Error B	64	32.34	0.51	

Appendix Table 31

Anova for %N As Affected by P Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	3.89		
Main Plots				
Dates	3	0.29	0.10	3.33
Replications	2	0.16	0.08	2.67
Error A	6	0.16	0.03	
Sub-Plots				
%N	8	1.56	0.20	10.00
%N x Dates	24	0.59	0.02	1.00
Error B	64	1.13	0.02	

Appendix Table 32

Anova for %P As Affected by P Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	11.72		
Main Plots				
Dates	3	2.30	0.77	11.00
Replications	2	0.33	0.17	2.43
Error A	6	0.40	0.07	
Sub-Plots				
%P	8	4.65	0.58	11.60**
%P x Dates	24	0.85	0.04	0.80
Error B	64	3.19	0.05	

Appendix Table 33

Anova for %K As Affected by P Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	5.08		
Main Plots				
Dates	3	1.14	0.38	3.17
Replications	2	1.28	0.64	5.33
Error A	6	0.70	0.12	
Sub-Plots				
%K	8	0.39	0.05	2.50
%K x Dates	24	0.45	0.02	1.00
Error B	64	1.12	0.02	

Appendix Table 34

Anova for Visual Ratings As Affected by K Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	48.94		
Main Plots				
Dates	3	1.72	0.57	3.80
Replications	2	2.02	1.01	6.73
Error A	6	0.92	0.15	
Sub-Plots				
K(VR)	8	35.69	4.46	44.60**
K(VR) x Dates	24	2.00	0.08	0.80
Error B	64	6.59	0.10	

Appendix Table 35

Anova for Dry Weight Yields As Affected by K Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	8.08		
Main Plots				
Dates	3	0.88	0.29	4.83
Replications	2	1.03	0.52	8.67
Error A	6	0.36	0.06	
Sub-Plots				
K(DW)	8	3.12	0.39	13.00**
K(DW) x Dates	24	0.63	0.03	1.00
Error B	64	2.06	0.03	

Appendix Table 36

Anova for Chlorophyll Content As Affected by K Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	70.55		
Main Plots				
Dates	3	8.77	2.92	13.90**
Replications	2	0.48	0.24	1.14
Error A	6	1.25	0.21	
Sub-Plots				
K(CC)	8	15.24	1.91	3.35**
K(CC) x Dates	24	8.08	0.34	0.60
Error B	64	36.73	0.57	

Appendix Table 37

Anova for %N As Affected by K Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	25.63		
Main Plots				
Dates	3	18.12	6.04	75.50**
Replications	2	0.04	0.02	0.25
Error A	6	0.49	0.08	
Sub-Plots				
%N	8	2.38	0.30	7.50**
%N x Dates	24	1.80	0.08	2.00
Error B	64	2.80	0.04	

Appendix Table 38

Anova for %P As Affected by K Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	38.19		
Main Plots				
Dates	3	0.84	0.28	0.90
Replications	2	0.45	0.23	0.74
Error A	6	1.86	0.31	
Sub-Plots				
%P	8	1.01	0.13	0.25
%P x Dates	24	0.64	0.03	0.06
Error B	64	33.39	0.52	

Appendix Table 39

Anova for %K As Affected by K Levels (Glasshouse)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	44.18		
Main Plots				
Dates	3	2.69	0.90	30.00
Replications	2	0.28	0.14	4.67
Error A	6	0.15	0.03	
Sub-Plots				
%K	8	40.11	5.01	501.00**
%K x Dates	24	0.42	0.02	2.00
Error B	64	0.53	0.01	

Appendix Table 40

Anova for Visual Ratings As Affected by N Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	999.19		
Main Plots				
Dates	3	0.84	0.28	1.75
Replications	2	0.34	0.17	1.06
Error A	6	0.94	0.16	
Sub-Plots				
N(VR)	8	145.62	18.13	259.00**
N(VR) x Dates	24	2.60	0.11	1.57
Error B	64	4.22	0.07	

Appendix Table 41

Anova for Dry Weight As Affected by N Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	39.58		
Main Plots				
Dates	3	0.002	0.001	0.50
Replications	2	0.11	0.005	2.50
Error A	6	0.01	0.002	
Sub-Plots				
N(DW)	8	38.74	4.84	484.00**
N(DW) x Dates	24	0.03	0.001	0.10
Error B	64	0.69	0.01	

Appendix Table 42

Anova for Chlorophyll Content As Affected by N Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	1184.22		
Main Plots				
Dates	3	27.98	9.33	7.23
Replications	2	2.32	1.16	0.90
Error A	6	7.75	1.29	
Sub-Plots				
N(CC)	8	1098.70	137.34	228.90**
N(CC) x Dates	24	8.99	0.37	0.62
Error B	64	38.48	0.60	

Appendix Table 43

Anova for %N As Affected by N Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	118.96		
Main Plots				
Dates	3	14.80	4.93	49.30**
Replications	2	0.27	0.14	1.40
Error A	6	0.60	0.10	
Sub-Plots				
N Levels	8	90.53	11.32	125.78**
N x Dates	24	6.78	30.78	342.00**
Error B	64	5.98	0.09	

Appendix Table 44

Anova for %P As Affected by N Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	2.61		
Main Plots				
Dates	3	0.26	0.09	4.50
Replications	2	0.12	0.06	3.00
Error A	6	0.13	0.02	
Sub-Plots				
P Levels	8	0.27	0.03	3.00**
P x Dates	24	0.98	0.04	4.00**
Error B	64	0.85	0.01	

Appendix Table 45

Anova for %K As Affected By K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	21.13		
Main Plots				
Dates	3	0.45	0.15	7.50
Replications	2	0.28	0.14	7.00
Error A	6	0.11	0.02	
Sub-Plots				
K Levels	8	17.51	2.19	73.00**
K x Dates	24	0.56	0.02	0.67
Error B	64	2.22	0.03	

Appendix Table 46

Anova for Visual Ratings As Affected by P Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	126.73		
Main Plots				
Dates	3	1.04	0.35	3.50
Replications	2	0.51	0.26	2.60
Error A	6	0.62	0.10	
Sub-Plots				
P(VR)	8	120.50	15.06	376.50**
P(VR) x Dates	24	1.19	0.05	1.25
Error B	64	2.87	0.04	

Appendix Table 47

Anova for Dry Weights As Affected by P Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	13.72		
Main Plots				
Dates	3	4.68	1.56	52.00**
Replications	2	0.47	0.24	8.00
Error A	6	0.16	0.03	
Sub-Plots				
P(DW)	8	6.25	0.78	39.00**
P(DW) x Dates	24	0.72	0.03	1.50
Error B	64	1.44	0.02	

Appendix Table 48

Anova for Chlorophyll Content As Affected by P Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	212.26		
Main Plots				
Dates	3	7.31	2.44	3.17
Replications	2	0.32	0.16	0.21
Error A	6	4.64	0.77	
Sub-Plots				
P(CC)	8	166.99	20.87	53.51**
P(CC) x Dates	24	7.95	0.33	0.85
Error B	64	25.05	0.39	

Appendix Table 49

Anova for %N As Affected by P Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	17.64		
Main Plots				
Dates	3	0.67	0.22	1.10
Replications	2	0.06	0.03	0.15
Error A	6	1.19	0.20	
Sub-Plots				
%N	8	6.50	0.81	6.75**
%N x Dates	24	1.31	0.05	0.42
Error B	64	7.91	0.12	

Appendix Table 50

Anova for %P As Affected by P Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	1.46		
Main Plots				
Dates	3	0.16	0.0533	5.33
Replications	2	0.09	0.0450	4.50
Error A	6	0.06	0.0100	
Sub-Plots				
%P	8	0.69	0.0863	18.76**
%P x Dates	24	0.16	0.0067	1.46
Error B	64	0.30	0.0046	

Appendix Table 51

Anova for %K As Affected by P Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	2.55		
Main Plots				
Dates	3	0.0013	0.0004	0.0172
Replications	2	0.0073	0.0037	0.1588
Error A	6	0.14	0.0233	
Sub-Plots				
%K	8	1.31	0.16	16.00**
%K x Dates	24	0.21	0.01	1.00
Error B	64	0.88	0.01	

Appendix Table 52

Anova for %P As Affected by K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	1.07		
Main Plots				
Dates	3	0.41	0.14	14.00
Replications	2	0.02	0.01	1.00
Error A	6	0.04	0.01	
Sub-Plots				
%P	8	0.09	0.01	1.00
%P x Dates	24	0.20	0.01	1.00
Error B	64	0.54	0.01	

Appendix Table 53

Anova for %K As Affected by K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	14.89		
Main Plots				
Dates	3	1.60	0.5333	19.98*
Replications	2	0.51	0.2550	9.55*
Error A	6	0.16	0.0267	
Sub-Plots				
%K	8	10.93	1.3663	379.53**
%K x Dates	24	1.46	0.0608	16.89*
Error B	64	0.23	0.0036	

Appendix Table 54

Anova for Chlorophyll Content As Affected by K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	67.89		
Main Plots				
Dates	3	1.16	0.39	0.51
Replications	2	1.56	0.78	1.03
Error A	6	4.57	0.76	
Sub-Plots				
K(CC)	8	10.96	1.37	3.04
K(CC) x Dates	24	21.12	0.88	1.96
Error B	64	28.52	0.45	

Appendix Table 55

Anova for %N As Affected By K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	19.07		
Main Plots				
Dates	3	4.51	1.50	37.50**
Replications	2	0.55	0.28	7.00
Error A	6	0.25	0.04	
Sub-Plots				
%N	8	1.18	0.15	1.00
%N x Dates	24	3.21	0.13	0.87
Error B	64	9.37	0.15	

Appendix Table 56

Anova for Visual Ratings As Affected by K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	102.56		
Main Plots				
Dates	3	0.52	0.17	0.53
Replications	2	6.22	3.11	9.72
Error A	6	1.93	0.32	
Sub-Plots				
K(VR)	8	82.54	10.32	73.71**
K(VR) x Dates	24	2.17	0.09	0.64
Error B	64	9.18	0.14	

Appendix Table 57

Anova for Dry Weights As Affected by K Levels (Field)

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	4.67		
Main Plots				
Dates	3	0.07	0.02	2.00
Replications	2	0.55	0.28	28.00**
Error A	6	0.03	0.01	
Sub-Plots				
K(DW)	8	3.05	0.38	38.00**
K(DW) x Dates	24	0.13	0.01	1.00
Error B	64	0.84	0.01	

Appendix Table 58

Anova for Visual Ratings As Affected by Varying P and K Levels

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	8.19		
Main Plots				
Dates	3	0.06	0.02	0.12
Replications	2	0.17	0.09	0.53
Error A	6	1.02	0.17	
Sub-Plots				
P	2	0.78	0.39	7.80**
K	2	0.14	0.07	1.40
P x K	4	1.42	0.36	7.20**
P x Dates	6	0.35	0.06	1.20
K x Dates	6	0.27	0.05	1.00
P x K x Dates	12	0.88	0.07	1.40
Error B	64	3.10	0.05	

Appendix Table 59

Anova for Dry Weights As Affected by Varying Levels of P and K

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	9.77		
Main Plots				
Dates	3	8.47	2.8233	141.17**
Replications	2	0.11	0.0550	2.75
Error A	6	0.12	0.0200	
Sub-Plots				
P	2	0.10	0.0500	4.27*
K	2	0.03	0.0150	1.28
P x K	4	0.03	0.0075	0.64
P x Dates	6	0.06	0.0100	0.85
K x Dates	6	0.06	0.0100	0.85
P x K x Dates	12	0.04	0.0033	0.28
Error B	64	0.75	0.0117	

Appendix Table 60

Anova for Chlorophyll Content As Affected by Varying P and K Levels

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	132.88		
Main Plots				
Dates	3	57.27	19.09	39.77**
Replications	2	1.56	0.78	1.63
Error A	6	2.87	0.48	
Sub-Plots				
P	2	1.90	0.95	1.46
K	2	11.43	5.72	8.80**
P x K	4	5.48	1.37	2.11
P x Dates	6	2.17	0.36	0.55
K x Dates	6	2.88	0.48	0.74
P x K x Dates	12	5.77	0.48	0.74
Error B	64	41.55	0.65	

Appendix Table 61

Anova for %N As Affected by Varying P and K Levels

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	20.10		
Main Plots				
Dates	3	15.33	5.11	255.50**
Replications	2	0.29	0.15	7.50*
Error A	6	0.09	0.02	
Sub-Plots				
P	2	0.14	0.07	1.75
K	2	0.18	0.09	2.25
P x K	4	0.62	0.16	4.00**
P x Dates	6	0.28	0.05	1.25
K x Dates	6	0.24	0.04	1.00
P x K x Dates	12	0.59	0.05	1.25
Error B	64	2.34	0.04	

Appendix Table 62

Anova for %P As Affected by Varying Levels of P and K

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	0.8300		
Main Plots				
Dates	3	0.1541	0.0514	10.0784**
Replications	2	0.0381	0.0191	3.7451
Error A	6	0.0304	0.0051	
Sub-Plots				
P	2	0.1355	0.0678	15.0667**
K	2	0.0224	0.0112	2.4889
P x K	4	0.0192	0.0048	1.0667
P x Dates	6	0.0144	0.0024	0.5333
K x Dates	6	0.0147	0.0025	0.5556
P x K x Dates	12	0.1340	0.0112	2.4889*
Error B	64	0.2878	0.0045	

Appendix Table 63

Anova for %K As Affected by Varying Levels of P and K

Source of Variation	d.f.	S.S.	M.S.	F
Total	107	14.38		
Main Plots				
Dates	3	0.34	0.11	1.57
Replications	2	0.03	0.02	0.29
Error A	6	0.44	0.07	
Sub-Plots				
P	2	0.31	0.16	1.60
K	2	5.87	2.94	29.40**
P x K	4	0.08	0.02	0.20
P x Dates	6	0.23	0.04	0.40
K x Dates	6	0.50	0.08	0.80
P x K x Dates	12	0.42	0.04	0.40
Error B	64	6.16	0.10	

Appendix Figure 73.

A. Effects of varying N levels under glasshouse conditions.

B. Effects of varying N levels under outdoor environment conditions.

A

B

Appendix Figure 74.

A. Effects of varying P levels under glasshouse conditions.

B. P deficiency symptoms.

A

B

Appendix Figure 75.

A. Effects of varying P levels under outdoor environment conditions.

B. P deficiency symptoms (outdoor environment)

A

B

Appendix Figure 76.

A. Effects of varying K levels under glasshouse conditions.

B. K deficiency symptoms (glasshouse).

A

B

Appendix Figure 77.

A. Effects of varying K levels under outdoor environment conditions.

B. K deficiency symptoms (outdoor environment).

A

B

BIBLIOGRAPHY

Adams, W. A., P. J. Bryan, G. E. Walker. 1974. Effects of cutting height and nitrogen nutrition on growth pattern of turfgrasses. Proceedings of the Second International Turfgrass Research Conference, pp. 131-144.

Beard, J. B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, N. J.

Bell, R. S. and J. A. DeFrance. 1944. Influence of fertilizers on the accumulation of roots by closely clipped bentgrasses and on the quality of turf. Soil Sci. 58:17-24.

Benson, N. and R. M. Barnette. 1939. Leaching studies with various sources of nitrogen. Journal of Amer. Soc. Agron. 31:44-54.

Bidwell, R. G. S. 1974. Plant Physiology. McMillan Publishing Co., Inc., New York.

Boeker, P. and W. O. Von Boberfield. 1974. Influence of various fertilizers on root development in a turfgrass mixture. Proceedings of the Second International Turfgrass Research Conference, pp. 99-103.

Boober, L. J. 1962. Liquid Fertilization of Turfgrass. Calif. Turfgrass Culture 12(3):17-18.

Bould, C. 1964. Leaf analysis in relation to raspberry nutrition. Plant Anal. and Fert. Problems. Amer. Soc. Hort. Sci., pp. 54-67.

Bradshaw, A. D., M. V. Chadwick, D. Jowett, R. W. Lodge and R. W. Swaydon. 1960. Experimental investigations into the mineral nutrition of serveral grass species. Part III. Phosphate level. Jour. of Ecology 48:631-637.

Branson, R. L. 1966. Better answers with soil and plant analysis. Calif. Turfgrass Culture 16(1):1-2.

Bredakis, E. J. 1963. Leachable nitrogen from soils incubated with turfgrass fertilizers. Agron. J. 55:145-146.

Brown, C. S. and P. R. Belyea. 1958. High nitrogen increases potash needs of grasses. Better Crops with Plant Food. Distributed by The American Potash Institute. Reprint DD-11-58.

Brown, K. W., R. L. Duble, and J. C. Thomas. 1977. Influence of management and season on fate of N applied to golf greens. Agron. J. 69:667-671.

Cataldo, D. A., L. E. Schrader and V. L. Youngs. 1974. Analysis by digestion and colorimetric assay of total nitrogen in plant tissues high in nitrate. Crop Sci. 14(6):854-856.

Chapman, H. D. and P. F. Pratt. 1961. Methods of Analysis for Soils, Plants and Waters. University of California.

Cheesman, V. H., E. C. Roberts, and L. H. Tiffany. 1965. Effects of nitrogen level and osmotic pressure of the nutrient solution on incidence of Puccinia graminis and Helminthosporium sativum infection in Merion Kentucky bluegrass. Agron. J. 57:599-602.

Clements, H. F. 1964. Interactions of factors affecting yield. Ann. Rev. Pl. Physiol. 15:409-442.

Coleman, N. T., J. T. Thorup, and W. A. Jackson. 1960. Phosphate-sorption reactions that involve exchangeable Al. Soil Sci. 90:1.

Davidson, O. W. 1946. Large-scale soil-less culture for plant research. Soil Science 62:71-86.

DeFrance, J. A. 1938. The effect of different fertilizer ratios on colonial, creeping and velvet bentgrass. Proc. of the Amer. Soc. Hort. Sci. 36:773-780.

Dubey, H. D. and R. L. Rodriquez. 1970. Effect of dyrene and maneb on nitrification and ammonification, and their degradation in tropical soils. Soil Sci. Soc. Am. Proc. 34:435-439.

Duble, R. 1976. Fall fertilization. Turfgrass Times 12(5):22-24.

________ 1977a. Leaf analysis - a back-up to soil testing. Turfgrass Times 13(1):14-17.

________ 1977b. Turf nutrition: fertilizationis not the only consideration. Turfgrass Times 13(3):21-23.

Duff, D. T. 1974. Influence of fall nitrogenous fertilization on the carbohydrates of Kentucky bluegrass. Proceedings of the Second International Turfgrass Research Conference, pp. 112-119.

Elkins, C. B. and C. S. Hoveland. 1977. Soil oxygen and temperature effect on tetany potential of three annual forage species. Agron. J. 69:626-628.

Epstein, E. 1972. Mineral Nutrition of Plants: Principles and Perspectives. Wiley and Sons Inc., N. Y.

Farhoomand, M. B. and L. A. Peterson. 1968. Concentration and content. Agron. J. 60:708-709.

Freeman, T. E. 1964. Influence of nitrogen on severity of Piricularia grisea infection of St. Augustinegrass. Phytopathology 54:1187-1189.

Gilbert, W. B. and D. L. Davis. 1967. Relationship of potassium nutrition and temperature stresses on turfgrasses. Agron. Abstracts, p. 52.

Gilliam, J. W. 1970. Hydrolysis and Uptake of Pyrophosphate by Plant Roots. Soil Sci. Soc. Amer. Proc. 34:83-86.

Goss, R. L. and C. J. Gould. 1967. The effect of potassium on turfgrass and its relationship to turfgrass disease. Agron. Abstracts, p. 52.

Graber, L. F. 1931. Food reserves in relation to other factors limiting the growth of grasses. Plant Phys. 6:43-71.

Hall, J. R. and R. W. Miller. 1974. Effects of P, season, and method of sampling in foliar analysis of Kentucky bluegrass. Proc. Second Ann. Turfgrass Res. Conf., pp. 155-171.

Harrison, C. M. 1931. Effect of cutting and fertilizer applications on grass development. Plant Phys. 6:669-685.

Hoagland, D. R. and D. I. Arnon. 1950. The Water-Culture Method for Growing Plants without Soil. Calif. Agric. Expt. Sta., Circular 347.

Holt, E. C. and R. L. Davis. 1948. Differential responses of Arlington and Norbeck bentgrasses to kinds and rates of fertilizers. Journal of Amer. Soc. of Agron. 40:282-284.

Hull, R. J. and L. M. Smith. 1974. Photosynthate translocation and metabolism in Kentucky bluegrass turf as a function of fertility. Proceedings of the Second International Turfgrass Research Conference, pp. 186-195.

Hylton, L. O., A. Ulrich, and D. R. Cornelius. 1967. Potassium and sodium interrelations in growth and mineral content of Halian ryegrass. Agron. J. 59:311-314.

Hylton, L. O., A. Ulrich, D. R. Cornelius and K. Okhi. 1965. Phosphorus nutrition of Italian Ryegrass relative to growth moisture content, and mineral constituents. Agron. J. 57:505-508.

Jackson, J. E., M. E. Walker and R. L. Carter. 1959. Nitrogen, phosphorus, and potassium requirements of coastal bermudagrass on a Tifton Loamy Sand. Agron. J. 51:129-131.

Joham, H. E. 1951. The nutritional status of the cotton plant as indicated by tissue tests. Plant Physiol. 26:76-89.

Johnson, G. V. 1974. Simple procedure for quantitative analysis of turfgrass color. Agron. J. 66:457-459.

Jones, D. I. H., G. A. P. Griffith, and R. J. K. Walters. 1965. The effect of nitrogen fertilizers on the water-soluble carbohydrate content of grasses. J. Agric. Sci. 64:323-328.

Jordan, C. W., C. E. Evans, and R. D. Rouse. 1966. Coastal bermudagrass response to applications of P and K as related to P and K levels in the soil. Soil Science Society of America Proc. 30:477-480.

Juska, F. V. and A. A. Hanson. 1967. Effect of nitrogen sources, rates, and time of application on the performance of Kentucky bluegrass turf. American Society for Horticultural Science. 90:413-419.

Juska, F. V., A. A. Hanson, and C. J. Erickson. 1965. Effects of phosphorus and other treatments on the development of Red Fescue, Merion, and Common Kentucky bluegrass. Agron. J. 57:75-78.

Juska, F. V. and A. A. Hanson. 1967. Phosphorus and its relationship to turfgrasses and Poa annua L. Calif. Turfgrass Culture. 17(4): 27-29.

__________ and J. J. Murray. 1974. Performance of bermudagrass in the transition zone as affected by potassium and nitrogen. Proceedings of the Second International Turfgrass Research Conference, pp. 149-154.

King, J. W. and C. R. Skogley. 1969. Effect of nitrogen and phosphorus placements and rates on turfgrass establishment. Agron. J. 61:4-6.

Knoop, W. E. 1972. Turf Nutrition. Weeds, Trees, and Turf 11(2):14.

Laidlaw, R. A. and S. G. Reid. 1952. Analytical studies on the carbohydrates of grasses and clovers. I. - Development of methods for the estimation of the free sugar and fructosan contents. J. Sci. Fd. Agric. 3:19-25.

Landua, D. P., A. R. Swoboda, and G. W. Thomas. 1973. Response of coastal bermudagrass to soil applied sulfur, magnesium and potassium. Agron. J. 65:541-544.

Lundegardh, H. 1943. Leaf analysis as a guide to soil fertility. Nature 151:310-311.

__________ 1951. "Leaf Analysis" (English translation by R. L. Mitchell). Hilger and Watts Ltd., London, 176 pp.

Mackenzie, A. J. 1967. Plant analysis as an aid to cotton fertilization. Soil Test and Plant Anal. Part II, Soil Sci. Soc. Amer. Special Pub. No. 2, pp. 25-31.

Madison, J. H. and A. H. Andersen. 1963. A chlorophyll index to measure turfgrass response. Agron. J. 55:461-464.

Mahdi, Z. and V. T. Stoutemyer. 1953. A method of measurement of populations in dense turf. Agron. J. 45:514-515.

Mantell, A. and G. Stanhill. 1966. Comparison of methods for evaluating the response of lawngrass to irrigation and nitrogen treatments. Agron. J. 58:465-468.

Markland, F. E. and E. C. Roberts. 1967. Influence of varying nitrogen and potassium levels on growth and mineral composition of *Agrostis palustris* Huds. Agron. Abstracts, p. 53.

Markland, F. E. and E. C. Roberts. 1969. Influence of nitrogen fertilizers on Washington Creeping bentgrass, *Agrostis palustris* Huds. I. Growth and Mineral Composition. Agron. J. 61:698-700.

Mazur, A. R. and T. D. Hughes. 1976. Chemical composition and quality of Penncross Creeping bentgrass as affected by ammonium, nitrate, and several fungicides. Agron. J. 68:721-723.

Menn, W. G. and G. G. McBee. 1970. A study of certain nutritional requirements for Tifgreen bermudagrass, utilizing a hydroponic system. Agron. J. 62:192-194.

Monroe, C. A., G. D. Coorts, and C. R. Skogley. 1969. Effects of nitrogen-potassium levels on the growth and chemical composition of Kentucky bluegrass. Agron. J. 61:294-296.

Murdoch, C. L. 1967. Heat tolerance of creeping bentgrass. Arkansas Farm Research, Arkansas Agric. Expt. Sta. Vol. 16.

Musser, H. B. 1948. Effects of soil acidity and available phosphorus on population changes in mixed Kentucky bluegrass-bent turf. Jour. of Amer. Soc. of Agron. 40:614-620.

McCool, M. M. and R. L. Cook. 1930. Rate of intake, accumulation and transformation of nitrate nitrogen by small grains and Kentucky bluegrass. Journal of Amer. Soc. of Agron. 22:757-764.

McVey, G. R. 1968. How seedlings respond to phosphorus. Weeds, Trees and Turf. 7(6):18-19.

Nittler, L. W. and T. J. Kenny. 1977. Effect of Ammonium to Nitrate Ratio on Growth and Pigment Development of Kentucky Bluegrass Cultivars. Agron. J. 69:577-579.

Noggle, G. R. and G. J. Fritz. 1975. Introductory Plant Physiology. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Nowakowski, T. Z. 1962. Effects of nitrogen fertilizers on total nitrogen, soluble nitrogen, and soluble carbohydrate contents of grass. J. Agric. Sci. 59:387-391.

Oertli, J. J. 1963. Nutrient disorders in turfgrass. California Turfgrass Culture 12(3):17-19.

Orth, P. G. and J. D. Dalton. 1973. Nutrient variability in grass tissue from two Dade County golf courses. Fla. Sta. Hort'l Soc., pp. 448-451.

Pellet, H. M. and E. C. Roberts. 1963. Effects of mineral nutrition on high temperature induced growth retardation of Kentucky bluegrass. Agron. J. 55:473-476.

Powell, A. J., R. E. Blaser, and R. E. Schmidt. 1967. Physiological and color aspects of turfgrasses with fall and winter nitrogen. Agron. J. 59:303-307.

Probesting, E. L. and J. G. Brown. 1954. Leaf analysis of differentially overcropped deciduous fruit trees. Hilgardia 23:125-153.

Ragland, J. L. and W. A. Seay. 1957. The effects of exchangeable calcium on the retention and fixation of phosphorus by clay fractions of soil. Soil Sci. Soc. Amer. Proc. 21:261.

Read, D. W. L. and R. Ashford. 1968. Effect of varying levels of soil and fertilizer phosphorus and soil temperature on the growth and nutrient content of bromegrass and reed canarygrass. Agron. J. 60:680-682.

Rieke, P. E. and B. G. Ellis. 1974. Effects of nitrogen fertilization on nitrate movements under turfgrass. Proceedings of the Second International Turfgrass Research Conference, pp. 120-130.

Robbins, W. R. 1946. Growing plants in sand cultures for experimental work. Soil Science 62:3-22.

Shive, J. W. 1915. A three salt nutrient solution for plants. Am. J. Bot. 2:157-160.

__________ and W. H. Martin. 1918. A comparative study of salt requirements for young and mature buckwheat plants in solution cultures. J. Agric. Res. 14:151-175.

Skogley, C. R. and J. W. King. 1968. Controlled release nitrogen fertilization of turfgrass. Agron. J. 60:61-64.

Smika, D. E., D. F. Heerman, H. R. Duke, and A. R. Batchelder. 1977. Nitrate-N percolation through irrigated sandy soil as affected by water management. Agron. J. 69:623-626.

Smith, P. F. 1962. Mineral analysis of plant tissues. Ann. Rev. Plant Physiol. 13:81-108.

Sturkie, D. G. and R. D. Rouse. 1967. Response of zoysia and Tiflawn bermuda to P and K. Agron. Abstracts, p. 54.

Suzuki, M. and L. B. MacLeod. 1977. Barley yields and tissue N, P, and K with high-low N supplyfor different growth periods. Agron. J. 69:695-700.

Tisdale, S. L. and W. L. Nelson. 1975. Soil Fertility and Fertilizers. McMillan Publishing Co., New York.

Ulrich, A. 1964. The relative constancy of the critical nitrogen concentration of sugar beet plants. Plant Anal. and Fert. Problems. Amer. Soc. Hort. Sci., pp. 371-391.

Ulrich, A. and F. J. Hills. 1967. Principles and practices of plant analysis. Soil Test. and Plant Anal., Part II, Soil Sci. Soc. Amer. Special Publ. No. 2, pp. 11-24.

Van Lieprop, W. M. 1976. Digestion procedures for simultaneous automated determination of NH_4, P, K, Ca and Mg in plant material. Can. J. Soil Sci. 56:425-432.

Waddington, D. V., E. L. Moberg, and J. M. Duich. 1972. Effect of N source, and K rate on soil nutrient levels and the growth and elemental composition of Penncross Creeping Bentgrass, Agrostis palustris Huds. Agron. J. 64:562-566.

Walker, R. H. and C. Y. Ward. 1974. Influence of N and K nutrition on net photosynthesis, dark respiration, and carbohydrates in centipedegrass. Proceedings of the Second International Turfgrass Research Conference, pp. 196-208.

Welch, L. F. and A. D. Scott. 1960. Nitrification of fixed ammonium in clay minerals as affected by added potassium. Soil Sci. 90:79.

Woodhouse, W. W., Jr. 1969. Long-term fertility requirements of coastal bermudagrass. II. Nitrogen, Phosphorus, and Lime. Agron. J. 61:251-256.